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KNOWING THROUGH NARRATIVES: THE ROLE OF KNOWLEDGE WITHIN THE TECHNOLOGICAL INNOVATION PROCESS IN THE UK UPSTREAM OIL AND GAS INDUSTRY

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ABSTRACT

The aim of this research was to further understanding of the role of knowledge and knowledge-based processes within the process of technological innovation within the UK upstream oil and gas industry.

The scope of the research encompassed three groups of actors within the innovation process: technology providers, enablers and end users. The research employed a qualitative approach using narrative and semi-structured interviews as a method for data collection, and employed an analytical template to analyse the data which was developed by integrating elements of Soft Systems Methodology (SSM) with narrative schema. A hypertextual system was also developed to determine how the explicit knowledge of the actors within the innovation process could be codified and transferred.

The findings identify six knowledge-based processes present within the technological innovation process: knowledge acquisition and learning; knowledge transfer; knowledge storage and maintenance; knowledge creation; knowledge application and exploitation; and knowledge valuation and measurement. The research shows that different emphases are placed on the importance of these processes according to the role of each group of actors.

In relation to the forms and types of knowledge present within the innovation process, the procedural and declarative knowledge of the technology providers are identified as key sources for the creation of new technologies. However, the enabling organisation plays a critical role in the innovation process by acting as a conduit of knowledge between the technology providers and the end users. End users are identified as a source of conditional knowledge relating to the applications of new technologies, and provide essential support for the process through funding.

The research contributes to the understanding of the relationships which exist between the knowledge processes within the technological innovation process, and identifies an additional form of conditional knowledge used within the process. Methodological contributions are made in the application of snowball sampling; the development and application of the knowledge-based analytical template; the relationship between narrative schema and soft systems methodology; and the development and application of the hypertextual narrative system.

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CONTENTS

TABLES

FIGURES

APPENDICES

ABBREVIATIONS

BERR	Department for Business, Enterprise and Regulatory Reform
BIS	Department for Business, Innovation and Skills
boe	Barrels of oil equivalent/per day
CMPT	Centre for Marine and Petroleum Technology
CRINE	Cost Reduction Initiative for the New Era
DETR	Department of the Environment, Transport and Regions
DTI	Department of Trade and Industry
ENERG	European Network for Research in Geo-Energy
EPSRC	Engineering and Physical Science Research Council
EUs	End Users
FPAL	First Point Assessment Ltd
GDP	Gross Domestic Product
HMG	Her Majesty's Government
HMT	Her Majesty's Treasury
HSE	Health and Safety Executive
ICT	Information and Communication Technology
IEP	Infrastructure and Energy Projects Directorate
IFP	Institut Francais du Petrole
ILT	Industry Leadership Team
ITF	Industry Technology Facilitator
ITG	Innovation and Technology Group
KM	Knowledge Management
LOGIC	Leading Oil & Gas Industry Competitiveness
MTD	Marine Technology Directorate
NEST	Network for the Exploitation of Science and Technology
NOVA	Venture capital fund for oil and gas industry development

NTOG	National Training Organisation Group
OETB	Offshore Energy Technology Board
OGITF	Oil and Gas Industry Task Force
OKT	Organizational Knowledge Transfer
OSO	Offshore Supplies Office
PSTI	Petroleum Science and Technology Institute
SCM	Supply Chain Management
SERC	Science and Engineering Research Council
SIN	Systems Integration Model
SPN	Stretch Performance Network
SSM	Soft Systems Methodology
TF1	Task Force 1
TF2	Task Force 2
TPs	Technology Providers
UKCS	United Kingdom Continental Shelf
UKOOA	United Kingdom Offshore Operators Association

CHAPTER ONE: INTRODUCTION

‘All men by nature desire to know.’ (Aristotle)

1.1 Background

This research is an examination of the role of knowledge within the technological innovation process in the UK upstream oil and gas industry. The research issue can be perceived from two broad perspectives. Firstly a socio-economic perspective which emphasises the economic value of knowledge as well as the importance of the process of innovation within the context of the knowledge economy, and secondly a philosophical perspective which identifies a renewed value being placed upon narrative knowledge. These perspectives are discussed in greater detail in Chapter 2.

Over the last fifty or so years there can be seen to have been a range of far-reaching socio-economic changes which have affected and are continuing to affect the ways in which people live and work. These changes can be seen to be closely linked to developments in (and applications of) information and communication technologies (ICTs). As such these technologies may be seen as agents of social change. They have greatly influenced the development of what Bell refers to as the post-industrial society (Bell, 1999), what Castells dubbed the network society (Castells, 1996), and what has become known more recently as the knowledge economy (Rooney, Hearn & Ninan, 2005).

A wide variety of definitions of the knowledge economy have been developed by academics and practitioners (in both the public and private sectors) alike. For example the Department of Trade and Industry (now the Department for Business, Innovation and Skills) defines a knowledge (or knowledge-based) economy as: ‘one in which the generation and the exploitation of knowledge has come to play the predominant part in the creation of wealth. It is not simply about pushing back the frontiers of knowledge; it is also about the more effective use and exploitation of all types of knowledge in all manner of economic activity’ (DTI, 1998, p.1). Naturally, the definitions used within the various contexts reflect a range of differing social, political and economic agendas.

Available definitions indicate an understanding of a number of important factors which have a bearing on this research: the increased (and continually increasing) role played by ICTs in supporting knowledge-based processes (such as knowledge storage and transfer); the role of the individual in creating and using knowledge and the concomitant implicit value of that knowledge; and the value of the interaction between people in the form of networks (particularly in relation to their role as actors within the innovation process). These issues can also be seen to help to identify some of the characteristics of the new economy (Tapscott, 1995; Castells, 2001) and can also be seen to be present within the various definitions of the economy itself.

Although the knowledge economy itself frequently challenges understanding due to its complex nature, the advent of the knowledge economy points to a renewed appreciation of the role and value (in both a qualitative and quantitative sense) of knowledge and knowledge-based processes at a variety of different levels. At a national policy level, economic policies have been formulated in order to enable organisations of all types to understand and operate effectively within this new environment, such as those identified by The Scottish Office (now replaced by The Scottish Government) in 'Scotland: Towards the Knowledge Economy' (1999). In addition, The Organization for Economic Co-operation and Development (OECD) highlighted the importance of developing a better understanding of the knowledge economy: 'OECD economies are increasingly based on knowledge and information. Knowledge is now recognized as the driver of productivity and growth, leading to a new focus on the role of information technology and learning in economic performance. The term 'knowledge economy' stems from this fuller recognition of the place of knowledge and technology in modern OECD economies' (OECD, 1996, p.3).

The impact of the knowledge economy also exists at a number of other levels. At a sectoral level, inter-organisational relationships are affecting the ways in which whole industries operate. At an organisational level, organisations in all sectors are both reacting to and driving the knowledge economy by developing new methods of working in which the role and consequently the value of knowledge is much more overt. Lastly at a personal level, individuals as creators of knowledge are increasingly seen as the most valuable of organisational assets.

Despite its complex nature, this new socio-economic environment has a number of observed characteristics which help to differentiate it from previous agricultural and industrial environments. Although these will be discussed in more detail in the next chapter (the review of the literature), it is important to acknowledge two of these characteristics from the outset which are fundamental to the research itself.

Firstly, the contention already acknowledged of the importance of the role of knowledge itself within the current socio-economic context. In spite of the acknowledgement of the current socio-economic environment being based on that most intangible of assets (knowledge) it is the process by which knowledge is turned into a tangible asset (or indeed another form of intangible asset when considering process innovations) that is recognised as one of the most important elements of the new economy. Clearly then knowledge does not displace the importance of the tangible within the new economy. Instead, the new economy is an acknowledgement of the importance of knowledge in the development of tangibles.

Secondly, the characteristic of the importance placed on innovation within a knowledge-focussed economy. The World Bank emphasises the importance of this second point: 'Continuous, market-driven innovation is the key to competitiveness, and thus to economic growth, in the knowledge economy. This requires not only a strong science and technology base, but, just as importantly, the capacity to link fundamental and applied research; to convert the results of that research to new products, services, processes, or materials; and to bring these innovations quickly to market. It also entails an ability to tap into and participate in regional and global networks of research and innovation' (World Bank, 2002, p.21). This view of the importance of innovation is however not new and can be seen to be clearly linked to the Schumpeterian economic view (Schumpeter, 1934; 1942) which emphasises the role of innovation as a driving force of economic development.

What has changed within the current context is the development of a supporting infrastructure as Amidon (2003, p.115) suggests: 'There is ample evidence in the media of the blistering pace at which information technology is influencing the process of innovation by providing the electronic infrastructure within which ideas can be created and disseminated. Opportunities seem incalculable. Product life cycles and even industry life cycles are consolidating, merging, and converging. The challenge, of course, is how best to manage this environment in ways that lead to prosperous growth in the enterprise, the nation, and society as a whole.' In effect then, it is the technological innovations which have been made in the field of information and communication technologies which have helped to enable the development of this new economy.

However, the ubiquitous nature of the knowledge economy means that it is not only businesses which are affected in some way. Like the Scottish Government, BIS (The Department for Business, Innovation and Skills) acknowledges that the forces manifest in the knowledge economy create a need for strategies for both the public as well as the private sectors. Both the Scottish Government and BIS acknowledge that the changes in the economy not only impact on the way in which private sector organisations operate, but also the ways in which public sector bodies seek to provide services and consequently support the activities of the private sector. For example with specific reference to this research, public sector organisations may well perform the role of an actor within the innovation process (for example as an enabler of technological innovation) and as such may act to 'link' the innovation provider to the end user, both of whom may well be private sector organisations.

In line with the policies produced by public sector bodies, the work of theorists such as Castells (2000) and Amidon (2003) in the area of the knowledge economy also bear out these perspectives. Succinctly, Amidon (2003) identifies three key elements which she argues need to be understood if organisations are to prosper economically:

- 'Knowledge is the new, expandable source of economic wealth. There is an emerging recognition that the inherent intellectual assets, effectively exploited through innovation, are the most valuable resource of any country.
- Innovation encompasses the full spectrum, from creative idea generation through full profitable commercialization. Successful innovation depends on converting knowledge stocks and flows into marketable goods and services.
- Collaboration replaces the competitive (win/lose) paradigm, which is prevalent in many businesses today, with win/win benefits based on pooling competencies: knowledge, know-how and skills.'

(Amidon, 2003, pp.8-9)

These elements identified by Amidon (but which can also be seen to be reflected in the works of other theorists as well as policy-makers) embody the underpinning concepts pertinent to this research: the appreciation of the value of knowledge; the importance of the innovation process within the knowledge economy; and the need for new models of working which are based on networking, and knowledge sharing.

1.2 Research Problem and Justification for the Research

From the previous section, it can be seen that a number of interrelated challenges relating to both knowledge and innovation exist for organisations in all sectors. There is a need therefore for organisations to develop a better understanding of these concepts if they are to survive within this turbulent economic environment which is characterised by change (Vaill, 1996), and is predicated on the implicit understanding of the importance and value of knowledge. More specifically, because of the emergence of the knowledge economy there is a need to develop a better understanding of the role of knowledge in a variety of contexts including the innovation process (a process acknowledged as central to this economy), as well as the role of the innovation process itself within the knowledge economy.

In addition to the characteristics identified within the previous section, the OECD identifies a variety of factors which can be seen to collectively contribute to the formation and development of the knowledge economy: ‘In addition to knowledge investments, knowledge distribution through formal and informal networks is essential to economic performance. Knowledge is increasingly being codified and transmitted through computer and communications networks in the emerging “information society”. Also required is tacit knowledge, including the skills to use and adapt codified knowledge, which underlines the importance of continuous learning by individuals and firms. In the knowledge-based economy, innovation is driven by the interaction of producers and users in the exchange of both codified and tacit knowledge; this interactive model has replaced the traditional linear model of innovation’ (OECD, 1996, p.7).

Research into the innovation process is in itself not unique, and is discussed in more detail in the next chapter. For example one of the most notable experts in the field of innovation, Rogers (1995), identifies a number of research questions which may be addressed in order to improve understanding of the innovation process. Although these can be seen to be closely related to this research, there are however notable differences which can be seen to be critical to the importance of this research. Whereas Rogers is principally concerned with how the knowledge of innovations is shared through channels of communication after that innovation has been developed, this research examines the role of knowledge within the process of developing technological innovations. In addition Rogers does not acknowledge the importance of the context of the knowledge economy which makes innovation such an important process and because of this, does not specifically identify the importance of the role of knowledge (and knowledge-based processes) within these research questions.

More recently, work linking innovation and knowledge management has begun to emerge from the literature. However this has tended to focus on formalised knowledge management initiatives within specific organisational contexts. This research aims to address issues which have not been considered in prior studies, and these are discussed below.

1.3 Aim and Research Context

Specifically, the central aim of the research project is to further understanding of the role of knowledge within the technological innovation process within the UK upstream oil and gas industry. This research represents one attempt to develop a better understanding of this context by focussing specifically on the process of technological innovation, and the role of knowledge within that process. Critically, the previous section highlights several issues which drive both the need for this research, and the specific objectives raised by it.

In the previous section The OECD (1996) highlights three issues relevant to this research which manifest themselves as objectives for the research and are discussed in Section 1.4: the actors; the knowledge-based processes; and the forms and types of knowledge present within the innovation process. Furthermore the need to understand the innovation process and the role of knowledge within it is not limited to academic contexts (as evidenced by Vaill, 1996), and it is critical that practitioners also develop a better understanding of this process.

Thus this work seeks not only to inform debate concerning the concepts of innovation and knowledge-based processes (in line with the factors identified by the OECD above – see Section 1.4.4), but also to determine the nature of the knowledge-based interactions between the actors operating within this process (see Sections 1.4.2 and 1.4.5), and how the actors may be influenced by exposure to the explicit knowledge of others (see Sections 1.4.3 and 1.4.6).

While the justification for the examination of both knowledge and innovation is provided in the previous section, the sector was selected for two main reasons. Firstly because of its economic importance to the UK as a whole, and secondly because of the important role played by technological innovations within this sector. These factors are examined further within Appendix IV: Contextual Framework.

Critically in relation to the concept of the knowledge economy, the oil and gas extraction industry (incorporating both the onshore and offshore elements of the business) has been identified in a recent study by the University of Strathclyde (McNicoll et al, 2002) as a ‘knowledge industry’. The study uses four measures (the average NVQ level of Scottish labour points; the proportion of employees with NVQ level 4/5; the ratio of NVQs sold/NVQs bought; and the proportion of employees in occupations with high ICT content) to rank industries according to their knowledge intensity. However the study itself acknowledges one of the key debates concerning the knowledge economy: ‘Knowledge itself is not easily defined or quantifiable, and the simple existence of knowledge per se does not automatically provide economic benefits. Rather, knowledge must be used and applied in appropriate ways for it to become an essential element in the development of the knowledge economy’ (McNicoll et al, 2002, p.4). Thus, this research presents an attempt to develop a better understanding of the role of knowledge within a ‘knowledge industry’.

This issue is also identified by the BERR (now BIS) in determining competitiveness indicators: ‘Concentrating on the so-called new economy, or high tech/knowledge-intensive businesses, would therefore seriously understate the importance of the knowledge economy’ (2001, p.7). So the knowledge economy consists of all sectors, and not just sectors which are seen to be ‘knowledge intensive’. The acknowledgement of the importance of the application of knowledge can then be applied to all organisations in all sectors. Whether the industry is considered (using the various metrics developed by organisations such as the OECD) to be a ‘knowledge industry’ or not, what can clearly be identified is its contribution to the British economy generally. More specifically, the importance of the role of innovation (one of the defining characteristics of the knowledge economy) can also be recognised.

1.4 Research Questions

This aim naturally raises a number of specific objectives and research questions which are identified below, and are addressed within the thesis. The relationships between the overall aim of the research, the objectives and the research questions identified may be visualised as follows:

Aim: To develop further understanding of the role of knowledge within the technological innovation process within the UK upstream oil and gas industry	
Research Question 1: What prior research exists in the areas relevant to this research?	**Objective 1:** To conduct a literature search and subsequent review and analysis of material in disciplines relevant to this research.
Research Question 2: Who are the actors within the technological innovation process in the UK upstream oil and gas industry, what are their roles, and what is the nature of their knowledge-based interactions?	**Objective 2:** To identify actors within the technological innovation within the UK upstream oil and gas industry, develop generalisable typologies and characterisations of those actors and their roles, and to determine the nature and significance of their knowledge-based interactions.
Research Question 3: Can a methodology be developed to identify and examine the knowledge-based processes, and forms and types of knowledge within the technological innovation process?	**Objective 3:** To develop and apply a methodological approach by which knowledge-based processes, and forms and types of knowledge within the innovation process may be identified and examined.
Research Question 4: What knowledge-based processes occur within the technological innovation process, how do they manifest themselves, and what is their significance within this process?	**Objective 4:** To identify the knowledge-based processes which exist within the process of technological innovation, develop generalisable typologies and characterisations of those processes, determine the extent to which they manifest themselves and their significance within the technological innovation process.
Research Question 5: What forms and types of knowledge are utilised within the technological innovation process, how do they manifest themselves, and what is their significance within this process?	**Objective 5:** To identify the forms and types of knowledge present within the process of technological innovation, develop generalisable typologies and characterisations of those forms and types of knowledge, determine the extent to which they manifest themselves and their significance within the technological innovation process.
Research Question 6: Are the actors within the technological innovation process influenced by exposure to the explicit knowledge of other actors, and if so how can this knowledge be codified and transferred?	**Objective 6:** To acquire explicit knowledge of actors within the technological innovation process, and subsequently to develop a tool which may be used to store, structure and transfer that explicit knowledge relating to the process of technological innovation.

Table 1: Aim, Objectives and Research Questions

1.4.1 What prior research exists in the areas relevant to this research?

The need to identify and consider the relevance of prior work is an essential part of any research. The purpose of this research question and the associated objective is to acquire an understanding of the key themes, issues and relationships emerging from the literature as they relate to the main topics of the research. Thus, this research question is used to identify the remaining research questions which emerge from the literature and are presented below, and is achieved by conducting a search, review and analysis of the literature in the areas identified above.

A review of the areas core to this research (specifically the context provided by the knowledge economy; forms and types of knowledge; knowledge-based processes; and the innovation process) is provided in the next chapter. In addition to the core foci of the research of technological innovation and knowledge, the importance and interrelationships of prior research in three other key areas is also acknowledged.

Firstly, an understanding of the industrial environment within which the research is placed provides a background to the research itself and furthermore helps to contextualize the findings. A contextual framework which examines the development of the upstream oil and gas industry from a global and local perspective and examines the importance of technological innovation is provided in Appendix IV. Secondly, the development of the methodological approach (which itself forms the third research question stated in Section 1.4.3) is reliant on an understanding of social science generally, and more specifically the application of specific qualitative research methods. The methodological approach developed and applied within this research is presented in Chapter 3 of this thesis. Thirdly, a philosophical perspective for the research is considered throughout the thesis and is provided overtly in Section 2.4.

1.4.2 Who are the actors within the technological innovation process in the UK upstream oil and gas industry, what are their roles, and what is the nature of their knowledge-based interactions?

Although the number of actors within an industrial field of innovation are potentially very large (given the broad context of the current understanding of how innovation may be defined), actors (or players) within the innovation process can be characterised by their role. Three key roles can be identified from the literature: providers of innovation; enablers; and end users. Traditionally, these actors have often consisted of organisations such as universities and research organisations acting as innovation providers; technology brokers, trade associations and governmental organisations acting as enablers of innovation; and lastly both public and private sector organisations acting as the end users of the innovations themselves. However, these definitions do not take into consideration the roles of the various actors in relation to the knowledge-based processes present within the innovation process.

Given the relationships between the innovation process and the various knowledge-based processes (which shall be discussed in more detail in subsequent chapters), there is a need to understand the roles of the various actors in relation to the knowledge-based processes. In effect therefore these are actors not only within an innovation process, but actors within a knowledge system. As Holzner et al (1987, pp.182-183) suggest: 'The social system of knowledge is the complex of institutions, organizations, occupations, and their norms, social roles, and resources that constitute the social arrangements within which knowledge-related activities are conducted.'

This research question will therefore be achieved through using the literature in order to identify generalisable typologies and characterisations of the actors within the innovation process in relation to the forms, types and knowledge processes with which they engage. These will subsequently be applied to the analysis of the actors and their roles as presented in the fourth and fifth chapters of this thesis.

1.4.3 Can a methodology be developed to examine the knowledge-based processes, and forms and types of knowledge within the innovation process?

The third research question relates to the development of a novel research methodology for the collection, analysis and structuring of data relating to the role of knowledge within the innovation process. As stated above, there is a need for both academics and practitioners alike to develop a better understanding of the role of knowledge within the innovation process. Given the lack of prior research (which draws together the knowledge-based processes, forms and types within the innovation process) there is a need to develop new methodological approaches which are relevant to the specific aim of the research.

The intended purpose of developing this methodology is to explore the potential for the application of such a tool both by researchers seeking to apply narrative techniques for data capture and analysis, and by practitioners in the field of innovation who may benefit through the use of a novel method of sharing knowledge relating to the process of technological innovation itself. Specifically within the context of this research, the development and application of a novel methodology may allow for a greater depth of understanding of the innovation process within the UK upstream oil and gas industry. Additionally it will allow for the opportunity to test the potential of using narratives relating to the innovation process as a mechanism for storing and sharing knowledge relating to development of technological innovations within the UK upstream oil and gas industry.

Although the use of narrative will be discussed in greater detail within the methodology chapter it can be seen to be justified both in terms of the adopted philosophical perspectives, and because of the need for research into the development of narrative methodologies: 'Concomitant with the rise of the narrative paradigm and the growing number of narrative research reports…has been a noticeable need for studies dealing with narrative methodology in social science. In fact the use and application of this research method seems to have preceded the formalization of a philosophy and methodology parallel to practice. Frequently, moreover, narrative study has been criticized as being more an art than research: It seems based predominantly on talent, intuition, or clinical experience; defies clear order and systemization; and can hardly be taught' (Lieblich et al, 1998, p.1).

Within the context of research, Lieblich et al (1998) suggest that the use of narratives ‘can be viewed as an addition to the existing inventory of the experiment, the survey, observation, and other traditional methods, or as a preferred alternative to these “sterile” research tools’ (Lieblich et al, 1998, p.1).

This research question will be addressed by developing a methodological approach by which knowledge-based processes, and forms and types of knowledge within the innovation process may be examined. The development and application of this approach is addressed in detail in Chapter 3 of this thesis.

1.4.4 What knowledge-based processes occur within the technological innovation process, how do they manifest themselves, and what is their significance within this process?

The concept of developing an understanding of the role of knowledge from the perspective of a series of interrelated knowledge-based processes is central to the understanding of how knowledge may be formally managed, both in inter and intra organisational contexts. A variety of writers in the field have proposed a number of differing (yet clearly related) knowledge-based processes. Wiig, for example identifies four processes within his model (Wiig, 1993): creation and sourcing; compilation and transformation; dissemination; application and value realisation. Burnett et al (2004) suggest six key knowledge-based processes: acquisition and learning; storage and maintenance; application and exploitation; dissemination and transfer; knowledge creation; and measurement and valuation.

Again, despite the acknowledgement within the literature of the range of knowledge-based processes, no prior research exists which identifies these processes specifically within the context of the technological innovation process in the UK upstream oil and gas industry. Thus, this research aims to contribute to developing an understanding of the role of knowledge within the technological innovation process through the identification of the knowledge-based processes present within this context.

Furthermore, this research seeks to go beyond simply identifying these processes within this context. It also seeks to develop an understanding of how these processes manifest themselves within the technological innovation process, and their relative significance within this process.

1.4.5 What forms and types of knowledge are utilised within the technological innovation process, how do they manifest themselves, and what is their significance within this process?

Arguably much of the difficulty in defining what knowledge actually is has been due to the multitude of ways in which knowledge may be classified according to its type and form, although even then the use of the terms ‘type’ and ‘form’ need to be clarified. From the literature there can be seen to be little or no consensus on defining the existing types of knowledge, and naturally this has much to do with the broad range of perspectives presented on knowledge itself. For example from a socio-economic perspective, OECD identifies the following types of knowledge:

‘In order to facilitate economic analysis, distinctions can be made between different kinds of knowledge which are important in the knowledge-based economy: know-what, know-why, know-how and know-who. Knowledge is a much broader concept than information, which is generally the “know-what” and “know-why” components of knowledge. These are also the types of knowledge which come closest to being market commodities or economic resources to be fitted into economic production functions. Other types of knowledge – particularly know-how and know-who – are more “*tacit knowledge*” and are more difficult to codify and measure’ (OECD, 1996, p.12).

Clearly then the *types* of knowledge also have a bearing on the *forms* of knowledge which may also be identified in relation to the innovation process. For example, as Kay suggests: ‘Since ‘knowledge that’—the characteristic discoveries of natural science—is easily transmitted, one solution [to the problem of creating ‘knowledge-based competitive advantages’] is to continually innovate and stay one step ahead. And that kind of innovative capacity depends on knowledge that isn’t ‘knowledge that’, but ‘knowledge how’—i.e. tacit knowledge’ (Kay, 1999, p.13).

This concept of tacit knowledge has been attributed to Polanyi (1966; 1974) and is arguably the most influential of all the various models of the forms of knowledge. Polanyi proposes that there are various human behaviours which exist in a form which renders them ‘tacit’ due to their inaccessibility to consciousness. The concept of tacit knowledge as a form can be seen to affect the various types of knowledge. Ryle (1984, pp. 25-61) for example directly links tacit knowledge to ‘know-how’ and explicit knowledge to ‘know-that’. This model can also be seen to be closely related to other models such as Oakeshott’s (1947) distinction between technical knowledge (knowledge of rules) and practical knowledge (knowledge of skills), and Kolb's (1984) separation of two differing types of knowledge (knowledge about and knowledge by direct acquaintance) distinguished by how that knowledge is obtained (comprehension or apprehension).

While various definitions of both the forms and types of knowledge are presented within the literature (see Chapter 2), this research question specifically addresses the identification of the forms and types of knowledge present within the innovation process in the UK upstream oil and gas industry for which no prior research has been conducted. Like the previous research question, this research does not only seek to identify the various forms and types, but also to develop an understanding of how these forms and types manifest themselves within the knowledge-based processes, and also their relative significance within the technological innovation process itself.

1.4.6 Are the actors within the technological innovation process influenced by exposure to the explicit knowledge of other actors, and if so how can this knowledge be codified and transferred?

The first part of this question is based on an acknowledgement of the importance of the knowledge acquisition and learning from external sources to actors within the innovation process (Leonard, 1998) which is discussed further in Section 2.5.1.1. Furthermore this question highlights the importance of the conversion of tacit to explicit knowledge through externalisation in the form of narratives (thus building on the third research question relating to the development of the methodological approach) and in the subsequent conversion of that explicit knowledge back to tacit knowledge through internalisation as Nonaka and Takeuchi suggest: 'For explicit knowledge to become tacit, it helps if the knowledge is verbalized or diagrammed into documents, manuals, or oral stories. Documentation helps individuals internalize what they experienced, this enriching their tacit knowledge. In addition, documents or manuals facilitate the transfer of explicit knowledge to other people, thereby helping them experience the experiences of others indirectly' (1995, p.69).

Secondly, this question examines the potential application of ICTs and more specifically internet-based technologies to enable access to explicit knowledge in the form of narratives in order to transfer actors' knowledge of the innovation process. Thus, this research question further contributes to addressing the need (identified by Vaill, 1996) for practitioners to develop a better understanding of the innovation process itself.

Although it may appear that this part of the research question relates more to the socio-economic perspective provided by the knowledge economy (which both acknowledges the importance of the infrastructure provided by ICTs and the importance of knowledge itself), there can also be seen to be a clear link to the philosophical perspective of intertextuality provided by the poststructuralist movement (Kristeva, 1986).

Landow (1992) expands on this perspective in his development of the concept of what he describes as 'hypertextuality' in which he proposes the use of ICTs (and more specifically the use of hypertext) to provide an infrastructure within which the notion of intertextuality may be practically applied: 'Hypertext, an information technology consisting of individual blocks of text, or lexias, and the electronic links that join them, has much in common with recent literary and critical theory…The very idea of hypertextuality seems to have taken form at approximately the same time that poststructuralism developed, but their points of convergence have a closer relation than that of mere contingency, for both grow out of dissatisfaction with the related phenomena of the printed book and hierarchical thought' (1992, p.1). The practicalities of this approach are further echoed by Ryan (2001, p.7) who suggests that it is the mechanism of hypertext which provides a perfect tool for 'the implementation of intertextual relations.'

Like the development of the knowledge economy itself, it is the development of an infrastructure capable of supporting the complexity of hypertextuality which has meant that it is only relatively recently that these theoretical considerations could be practically applied. The use of hypertext as a narrative tool is in itself not new, as Dinkla suggests: 'Since the mid-1960s the narrative strategy of hypertext has been discussed in art. Since the 1970s Theodor Holm Nelson, who coined the term 'hypertext' as early as 1965, has pursued the idea of developing software which, like the library of Babel, contains all existing texts and this enables the user, when coming upon a reference he or she would like to follow up, to call up the respective text. Nelson defines 'hypertext' as 'non-sequential writing – text that branches and allows choices to the reader, best read at an interactive screen'' (Dinkla in: Rieser and Zapp (eds), 2002, p.31). However, there is very little research into the use of hypertextual narrative tools within the field of social science to examine works of narrative nonfiction (Branigan, 2001), and this research question seeks to address this issue.

This research question will be addressed by acquiring explicit knowledge of actors within the technological innovation process, and subsequently developing a tool which may be used to store, structure and transfer this explicit knowledge of the technological innovation process in the form of personal narratives. The development of this tool is detailed in Section 3.6.7 in Chapter 3, and screenshots of the tool are provided in Appendix III.

1.5 The Structure of the Thesis

This chapter has provided an introduction to the research topic by presenting perspectives relating to the role and significance of knowledge within the context of the knowledge economy. It has provided a rationale for the research by both emphasising the importance of technological innovation and (from a philosophical perspective) suggesting that the current (highly scientific) view of knowledge is only part of a larger world view which may also encompass narrative knowledge. More specifically the chapter provides the specific aim, objectives and research questions for the research itself.

The second chapter of the thesis goes on to present a review of literature relating to the disciplines which inform this research. Due to the nature of the research itself, it covers a number of distinct but related topics. The chapter aims to identify work already conducted in these areas, and to determine their significance in relation to this research. The aim of this is to develop an understanding not only of the significance of the literature within these disciplines (and of the literature to the research) but also of the relationships which exist between these disciplines. The primary foci of the chapter are: the development of the knowledge economy; the forms and types of knowledge; a philosophical perspective on knowledge provided by postmodernism and post-structuralism; the role and management of knowledge within an organisational context; and the technological innovation process. This chapter can also be seen to contribute substantially to addressing the first research question.

The third chapter gives an explanation and justification of the methodological approaches taken within the research. It provides a background to the two main research paradigms (positivism and phenomenology) and explains why a phenomenological approach was taken within this research. It details the stages within the research process from literature searching through to the application of the analytical templates. It also addresses the construction of the methodological tools and explains both how and why these were developed. A rationale is presented for the sampling process, and an explanation given for the data collection methods within the sample groups used. Lastly, the chapter provides an explanation of how the analytical tools developed formed the structure for the hypertextual system developed in order to address the sixth research question.

The fourth chapter presents the findings for the research pertaining to the examination of actors; the knowledge-based processes; and the types and forms of knowledge present within the technological innovation process (from the perspectives of the three previously identified groups of actors); and in relation to the actors' engagement with the hypertextual narrative system.

The fifth chapter presents the discussion relating to the findings presented in the previous chapter and specifically relates these findings back to the relevant literature. It identifies and discusses the key findings for the research.

Lastly, the sixth chapter concludes the thesis. It reflects on the contextual contributions made by the thesis, identifies limitations of the research, and provides suggestions for future research in related areas.

Four appendices are also provided. The first presents some additional background information on the end user and technology provider organisations who participated in the research. The second presents the user guide to the innovation narratives system developed in order to address the sixth objective. The third presents a sample of screenshots of the system. Lastly, a contextual framework for the research is provided in Appendix IV. It illustrates the importance the oil and gas industry has had (and continues to have) on the British economy. It emphasises the importance of the role of technological innovation to the development and exploitation of the UK Continental Shelf (UKCS). In addition it introduces many of the key players/actors within the UKCS who have been involved in technological innovation and other related activities.

CHAPTER TWO: REVIEW OF THE LITERATURE

‘Knowledge is the only instrument of production that is not subject to diminishing returns.’ (J.M. Clark)

2.1 Introduction

The purpose of this chapter is to provide a review of the literature relating to the disciplines which inform this research. The chapter aims to identify and examine work already conducted in these areas, and to determine their significance in relation to this research. The aim of this is to develop an understanding not only of the impact of the literature within these disciplines, but also of the relationships which exist between these disciplines. This chapter can also be seen to address the first research question: What prior research exists in the areas relevant to this research?

This research can be seen to examine the nature of two specific characteristics of the knowledge economy (the importance of knowledge and innovation) within a specific industry context. These elements are reflected within the following structure. Firstly, the chapter presents a review of the literature as it pertains to the development of the knowledge economy. This section provides the broad context within which the remaining literature is examined. Secondly, the chapter presents a number of perspectives on the forms and types of knowledge which have helped to form a variety of definitions of knowledge. The nature of knowledge from a philosophical perspective is discussed in the next section which examines the relationship between the postmodern and post-structuralist context and specific forms of knowledge relevant to this research, namely scientific and narrative knowledge. Having provided a broad examination of the concept of knowledge, the topic of knowledge management is introduced in Section 2.5 and presents the knowledge-based processes applied within the analytical template discussed in Chapter 3. The fourth section examines the development of innovation process models, and also highlights the key relationships between innovation and technological knowledge. Lastly, a concluding section summarises the key issues highlighted within the chapter and identifies the links between the literature review and the remaining chapters.

2.2 The Development of the Knowledge Economy

Castells states that ‘Towards the end of the second millennium of the Christian era several events of historical significance transformed the social landscape of human life’ (Castells, 1996, p.1). As stated in the previous chapter, these changes can be closely identified with the development of ICTs. However such a period of technology-driven socio-economic change is not unique, nor is its identification new. Toffler (1980) suggests the changes or transformations which are currently being experienced are not an isolated number of events, but are in fact only part of a number of ongoing paradigmatic societal shifts dating back thousands of years of which this is the third. These shifts or ‘waves’ (as Toffler refers to them) represent a change in approach to the ways in which resources are managed, and consequently the ways in which people work and live. Seen from a perspective of technological determinism where technology is a driver of social and cultural change, these changes can be identified with specific technological developments (for example Ellul, 1964; Heidegger, 1977; McLuhan and Zingrone, 1995) which are discussed in more detail later in this chapter.

Societal changes then cannot be observed as a gradual process of incremental developments, but as the result of (or in parallel with) periodic technological innovations which have occurred sporadically throughout history of which there can be little or no forewarning: ‘The history of life, as I read it, is a series of stable states, punctuated at rare intervals by major events that occur with great rapidity and help to establish the next stable era’ (Gould, 1980, p.226). Although the list of technologies which shape society is arguably almost limitless, as (it could be suggested) all technologies to some extent shape the societies which have produced them, a number of technologies have been identified by various writers as those being fundamental to socio-economic change. In relation to both the agricultural and industrial revolutions, socio-economic change can be seen to have been triggered by the development and application of two specific technologies: in the agricultural revolution, the plough; and in the industrial revolution, the steam engine. Scott (1985, p.16) states that ‘the theory holds that the basic features of culture and society are to be explained in terms of the unfolding of tendencies inherent in the determining industrial technology.’ In effect then, the development and application of new tools or processes (such as the plough and the steam engine) allow for new methods and practices of working and living, and so generate socio-economic change.

However, despite the acknowledged importance of these technologies, it is important to appreciate that they cannot be viewed as instruments of change in their own right: ‘Technology, by itself, is not the driving force of history. Nor, by themselves, are ideals or values. Nor is the class struggle. Nor is history merely a record of ecological shifts, demographic trends, or communications inventions. Economics alone cannot explain this or any other historical event. There is no ‘independent variable’ upon which all the other variables depend. There are only inter-related variables, boundless in complexity’ (Toffler, 1980, p.128).

According to Toffler (1980), the first ‘wave’ of change may be identified with the revolution in the management of agricultural resources approximately ten thousand years ago. This revolution in the domestication of both livestock and crops for food production moved human societies away from the relative unpredictability and mobility of hunting and gathering, and towards a greater degree of stability and control of their tangible resources. In the case of the agricultural revolution the development of a specific technology, the animal drawn plough, forever changed the way in which agricultural resources would be managed. In effect this moved humans from gathering food to producing food, as they replaced the tools for gathering with tools of production. The societal effects of this technological advancement were far reaching. Agricultural production became vastly more efficient by allowing greater areas of land to be cultivated by fewer people. This in turn created surpluses of resources which then had to be defended from being taken by other social groups, and arguably led to the creation of the nation state itself. Taken to an extreme, it can be argued that such simple yet significant technological advances in effect triggered a series of ongoing changes which have formed the present socio-economic climate: 'such inventions as the horse collar quickly led to the development of the modern world' (McLuhan & Watson, 1970, p.121).

These developments can be seen to have an affect on all levels of society: from the personal to the global. In the case of the agricultural revolution, the invention and application of a plough that could be pulled by animals meant that fewer people could farm more land. At a personal level, this change meant that people’s time was freed to perform other tasks or to do more in the same amount of time. Another effect of this revolution was that the resultant surplus of resources meant that people were no longer just producing for themselves, but could produce for others as well. This in turn meant that the land was capable of supporting more people, and as a result populations increased dramatically. This change had a socio-economic impact at a higher level through the establishment of a ‘social elite’ who had control of the surplus resources, and a working class who actually produced the resources. Within the context of the agricultural revolution the development of the plough helped to catalyse the notion and creation of nation states through the acknowledgement of the value of tangible assets such as land, animals and grain, and the need to protect them (Toffler, 1980).

Similarly in relation to the second wave, the industrial society borne from the industrial revolution, this perspective of technological determinism is hard to ignore despite its critics (for example Feenberg, 1999). However as with the first wave, the role of technology cannot be seen in isolation but rather as part of an inextricably related set of cultural and technological changes: ‘The exhaustion of Britain’s timber forests prompted the use of coal. In turn, this forced the mine shafts deeper and deeper until the old horse-driven pumps could no longer clear them of water. The steam engine was perfected to solve this problem, leading to a fantastic array of new technological opportunities’ (Toffler, 1980, p.128).

In the case of the industrial revolution, what principally began as an economic revolution gave rise to unprecedented social changes. The focus changed from the value placed on tangible assets in the form of raw or natural resources such as wood or land, to value placed on manufactured goods, such as linen and steel. The invention of the steam engine moved human societies from being largely agricultural (and consequently based in rural areas) to being highly industrialised and urbanised. Populations boomed across Europe as workers flooded into cities for work within the new factories. New classes emerged: the factory owners and the factory workers. Again, these changes can be clearly linked to technological developments as Marx acknowledges: ‘In acquiring new productive forces men change their mode of production, and in changing their mode of production they change their way of living - they change all their social relations. The hand-mill gives you society with the feudal lord; the steam-mill, society with the industrial capitalist' (Marx, 2005, p.166).

The invention of the steam engine and its subsequent application in a myriad of different manufacturing contexts from cotton mills to coal mining was the technological catalyst for change during the first industrial revolution. Once again, the increased efficiencies in production that were experienced as a result of the steam engine manifested themselves in surplus goods. However these goods were not only products in their natural state such as wool or barley, but manufactured goods such as cloth or bricks. Along with this technological development came a range of social issues. Work within the factories was often dangerous, and living conditions for the workers within the rapidly growing cities were poor. This revolution then saw the emergence of appreciation of a new asset: labour. Within this revolutionary context the value of the individual was based on their ability to follow an instruction such as working a loom, in order to produce a manufactured good, such as linen. As such the human capital value of an organisation was based on physicality rather than intellect: ‘Modern societies are defined first and foremost by their organisation of labour; that is, by their relationship to the external world, their use of machinery, the application of scientific methods, and the social and economic consequences of the rationalisation of production’ (Aron, 1967, p.15).

Although there can be little doubt that the technologies identified above have clearly impacted greatly on human social structure, Mcluhan and Zingrone suggest that the technologies which have been critical to socio-economic development have been those relating to communication, namely the phonetic alphabet, the printing press and the telegraph (McLuhan and Zingrone, 1995, pp.223-269). Although this perspective may sound rather dismissive, McLuhan and Zingrone are in fact suggesting that within given periods (the tribal age, the literate age, the print age, and the electronic age as they refer to them) the ways in which society communicated changed, and that these changes were driven by technological developments relating to communication. Indeed Postman echoes this sentiment stating that: ‘the printing press, the computer, and television are not therefore simply machines which convey information. They are metaphors through which we conceptualize reality in one way or another. They will classify the world for us, sequence it, frame it, enlarge it, reduce it, argue a case for what it is like. Through these media metaphors, we do not see the world as it is. We see it as our coding systems are. Such is the power of the form of information’ (Postman, 1979, p.39).

Consequently, these advances in communication provided the foundation for subsequent technological developments unrelated to communication. For example, McLuhan and Zingrone argue that the revolution in print driven by the development of moveable type was effectively a catalyst for the industrial revolution: ‘Movable type was archetype and prototype for all subsequent industrial development. Without phonetic literacy and the printing press, modern industrialism would be impossible’ (McLuhan and Zingrone, 1995, p.244). This can be seen to be particularly relevant to the current socio-economic environment in which information and communication technologies are providing organisations with much more effective methods of operating. Although ICTs do not in themselves embody the new economy, they can be seen to play a significant role in supporting it.

In addition to the socio-economic models changing, the role of knowledge within these models can also be seen to be changing. Whereas knowledge was seen as an external influence on traditional production functions such as land, labour, money and raw materials, knowledge is increasingly being seen as a production function in itself: ‘Investments in knowledge can increase the productive capacity of the other factors of production as well as transform them into new products and processes. And since these investments are characterised by increasing (rather than decreasing) returns, they are the key to long-term economic growth' (OECD, 1996, p.11).

It is important to note also that this current wave is being seen as being as important both socially and economically as the two previous waves. One significant element of the socio-economic changes which have occurred as a result of a technological development has been the acknowledgement of the value of different forms of tangible assets. The current revolution which is being experienced as a precursor to a period of stability (should this wave follow a similar model to previous waves) is however a clear departure from the two previous. The currently revolution suggests a synergy between the perspective of technological determinism proposed by McLuhan (1970; 1995), which is limited only to technologies relating to information and communication, and a broader perspective which suggests it also relates to the technologies of production of tangible assets. The current revolution now places value on the communication between individuals as a mechanism for the creation and sharing of intangible assets in the form of knowledge: 'What characterizes the current technological revolution is not the centrality of knowledge and information, but the application of such knowledge and information to knowledge generation and information processing/communication devices, in a cumulative feedback loop between innovation and the uses of innovation' (Castells, 1996, p.31).

A range of different terms have been used to characterise and to some extent try to understand the driving principles behind this current revolution. The information society; the knowledge economy; the digital economy; the information revolution: these terms have been widely adopted within both the public and private sectors throughout the world as a means of expressing an understanding of the nature of the current economic and social climate. Although meanings of all these terms are somewhat unclear (and are in fact often used interchangeably), they point towards a general shift in the understanding of what the defining characteristics of society are. The concomitant socio-economic change which has arguably been caused because of this revolution is a renewed understanding of the value of knowledge as an intangible asset: 'Knowledge is now recognised as the driver of productivity and economic growth, leading to a new focus on the role of information, technology and learning in economic performance' (OECD, 1996, p.3).

Castells (2000, p.28) suggests that the current socio-economic environment is one characterised by the transformation of culture by technology. Similarly Kelly (1998, p.2) identifies three distinguishing characteristics for this 'new' economy: 'It is global. It favors intangible things – ideas, information, and relationships. And it is intensely interlinked. These three attributes produce a new type of marketplace and society, one that is rooted in ubiquitous electronic networks.' In effect then, unlike previous waves, the present wave cannot be observed in the same way where there has been a technological development, a period of adjustment, and then (relative) stability. Instead, it is suggested that this present environment can be seen to be a wide range of ongoing technological developments with no inherent stability following. In part at least, this may be seen to be due to the rate of development of information and communication technologies.

Arguably the use of the term 'economy' in its application to the current wave is misguided. One of the most commonly used definitions of economics is that provided by Robbins (1935, p.16): 'a science which studies human behaviour as a relation between ends and scarce means which have alternative uses.' The knowledge economy, it is often noted, is not an economy of scarcity, but of abundance. What can be seen from the available definitions of the knowledge economy is agreement on a number of common factors: that people and their ability to generate and apply knowledge is fundamental to the economy; and there is an increased (and continually increasing) role played by information and communication technologies (ICTs) in supporting the information and knowledge-based processes (such as knowledge transfer). Indeed Boisot suggests that: 'These two revolutions in the complementary fields of information structuring and information sharing promise changes in the human condition as fundamental as those that accompanied the advent of settled agriculture or the harnessing of inanimate power to human purposes' (Boisot, 1998, p.206).

Although the use of terms such as 'knowledge economy' have been adopted relatively recently, the understanding of the social and economic value of knowledge is not new. Hayek (1945, p.519) identifies the key issue of integrating knowledge in order to provide an economic contribution: 'The peculiar character of the problem of a rational economic order is determined precisely by the fact that the knowledge of the circumstances of which we must make use never exists in concentrated or integrated form but solely as the dispersed bits of incomplete and frequently contradictory knowledge which all the separate individuals possess. The economic problem of society is thus not merely a problem of how to allocate "given" resources - if "given" is taken to mean given to a single mind which deliberately solves the problem set by these "data." It is rather a problem of how to secure the best use of resources known to any of the members of society, for ends whose relative importance only these individuals know.' However it has not been until relatively recently that adequate information and communication infrastructures have existed which have made possible the collation and sharing of knowledge, identified by Hayek (1945) as vital.

Similarly, the concept of innovation as an economic force was identified by Schumpeter around the same time (1934; 1939; 1942): '[I]n capitalist reality as distinguished from its textbook picture, it is not [price] competition which counts but competition from the new commodity, the new technology, the new source of supply, the new type of organization…-competition which commands a decisive cost or quality advantage and which strikes not at the margins of the profits and the outputs of the existing firms but at their foundations and their very lives' (1942, pp. 84-85).

A more recent perspective which echoes this sentiment while placing a more explicit value on knowledge is presented by Garvey and Williamson (2002, p.14) who state that: 'In the age of science, technology and mass communications, economic life is driven by a competitive search for advantage and profit based on the exploitation of new knowledge. All sectors of the modern economy depend for their survival and growth on maintaining and developing ideas, skills and products that increasingly require advanced scientific, technological and social scientific research.'

So in spite of an understanding of the roles and value of both knowledge and innovation, it can be suggested that the tools which were recognised as having the potential to catalyse and support the knowledge-based economy (i.e. information and communication technologies) were not sufficiently advanced to address the issue of knowledge sharing identified by Hayek (1945) despite acknowledgement of the role of an Internet-type network being made around the same time (Bush, 1945). In effect, it is the increased ability for people to share and/or transfer knowledge via ICTs that has been the most important function of the technology as Kelly suggests: 'Because communication – which in the end is what the digital technology and media are all about – is not just a sector of the economy. Communication *is* the economy' (Kelly, 1998, p.5). This point is further emphasised by Castells (1996, p.30) who states that '…unlike any other revolution, the core of the transformation we are experiencing in the current revolution refers to technologies of information processing and communication. Information technology is to this revolution what new sources of energy were to the successive industrial revolutions, from the steam engine to electricity, to fossil fuels, and even to nuclear power, since the generation and distribution of energy was the key element underlying the industrial society.'

Although the development of the information society and the knowledge economy appear to have been aided by the development of (and advances in) information and communication technologies (ICTs), it is perhaps overly simplistic to suggest that one has driven the other. There is a synergistic relationship between the emergent knowledge-based economy and advances in information and communication technology. Clarke suggests that: ‘The information and communications technology revolution and knowledge revolution fuel each other as it is only in the fusion of the electronic network infrastructure of the Internet and other digital systems and services, and the rapidly developing knowledge tools and systems in the knowledge-driven economy. That the full implications of electronic business and knowledge management to transform our lives can be fully realised’ (Clarke, 2001, p.191).

The role of information and communication technologies has proved such a significant contributor to the creation of the new economy that it has even been dubbed the digital economy (Tapscott, 1995). New information and communication technologies have allowed for the ready storage of explicit (or codified) knowledge, as well as its transfer between agents in both one-to-one and one-to-many environments. As a by-product of the application of ICTs to the management of knowledge (particularly declarative and experiential knowledge discussed later in this chapter), there has been an increase in the codification of knowledge in order to enable its access and transfer via digital environments. Paradoxically then, this shift from tacit knowledge to its codified explicit form has vastly increased the amount of information rather than knowledge: ‘All knowledge which can be codified and reduced to information can now be transmitted over long distances with very limited costs. It is the increasing codification of some elements of knowledge which have led the current era to be characterised as “the information society” – a society where a majority of workers will soon be producing, handing and distributing information and codified knowledge’ (OECD, 1996, p.13). The growth in knowledge work thus transcends traditional sectoral and industry divisions – even industries and roles which have been considered to be physical and manual in nature are increasingly knowledge-driven.

Information and communication technologies thus act to provide the technological infrastructure required for a global economy. DeLong and Summers (2001) suggest that technology is in fact the single most important characteristic of the knowledge-based economy: ‘The essence of the “new economy” is quickly stated. Compare our use of information technology today with our predecessors’ use of information technology half a century ago’ (DeLong and Summers, 2001, p.8).

This increase not only in the use of information and communication technologies, but the processing capacity is ensuring that evermore data, information and knowledge can be stored and transferred by individuals, groups and organisations, and this increase shows no sign of slowing down: ‘More than a generation ago Intel Corporation co-founder Gordon Moore noticed what has become Moore’s Law – that improvements on semiconductor fabrication allow manufacturers to double the density of transistors on a chip every eighteen months. The scale of investment needed to make Moore's Law hold has grown exponentially along with the density of transistors and circuits, but Moore's Law has continued to hold, and engineers see no immediate barriers that will bring the process of improvement to a halt anytime soon' (DeLong and Summers, 2001, p.8). Although extremely simplistic, Moore's Law emphasises the role of significant ongoing change within the current environment. In this revolution there has not been one technological advance which has changed society, and then society settles back. In this revolution, the technological changes and advances are constant and ongoing. However although such 'laws' are a useful heuristics in relation to the speed of development of technology, they do not indicate a qualitative use of the technology. As Brown and Duguid suggest: 'Digital technologies currently produce between one and two exabytes per year. It's hard to know, however, what such a sum might signify. After all, thirteen hundred words of gibberish and the Declaration of Independence are digitally equivalent. Storage does not correlate with significance, nor volume with value' (Brown and Duguid, 2000, p.xiii).

A critical effect on the use of ICTs within the knowledge economy has been on geography: 'The effect of location is diminished. Using appropriate technology and methods, virtual marketplaces and virtual organizations can be created that offer benefits of speed and agility, of round the clock operation and of global reach' (Skyrme, 1997). In previous economies, organisations' competitors and customers were often determined geographically. Organisations would offer their products and services within relatively localised markets. In addition, multi-national enterprises would be limited by how and when they could share knowledge and information internally through the application of 'traditional' methods of transfer such as postal services. Now information and communication technologies have acted to enable interactions between individuals who are geographically and temporally dispirit, which has in turn allowed for the creation and development of a global economy (Castells, 2001).

This global economy then presents a paradox to organisations: a potentially much larger marketplace for their products and services, combined with a higher degree of competition. Paradoxically then despite being labelled a global phenomenon, the geographical consideration to the development of the new economy has become far less important. As knowledge at an individual level is seen increasingly as a key economic resource at both organisational and national levels, so then the concept of knowledge at a localised geographical level becomes increasingly redundant. However, this is not to reject the concept of 'place' as valuable within this new context: 'Place still matters, and will for a long time to come. However, the new economy operates in a “space” rather than a place, and over time more and more economic transactions will migrate to this new space’ (Kelly, 1998, p.94). This redundancy can in part be seen to be due to the pervasiveness of information and communication technologies allowing collaboration between individuals who may be separated by geography. This instantly allows individuals to work in and from and increasingly diverse range of environments, which subsequently calls for a need to re-examine and extend concepts of work space to include these new patterns of work: ‘The office is no longer a place, it is a global system. Technology is eliminating the “place” in workplace. Home may be where the heart is, but increasingly the office is anywhere the head can be connected’ (Tapscott, 1995, p.65).

This situation clearly affects multinational organisations which may have physical offices spread throughout the world. Companies then are not limited by collaboration or competition with local organisations, but may form relationships with organisations located anywhere with adequate technological infrastructure in place. Cairncross emphasises the importance of this effect: ‘The death of distance as a determinant of the cost of communicating will probably be the single most important force shaping society in the first half of the next century. Technological change has the power to revolutionize the way people live, and this one will be no exception’ (Cairncross, 1997, p.1).

Obviously, the most significant defining characteristics of the knowledge-based economy is, naturally, knowledge itself: ‘In the new economy the key assets of the organization are intellectual assets, and they focus on the knowledge worker. This is causing companies around the world to develop new ways of measuring and managing their intellectual capital’ (Tapscott, 1996, p.46). Boisot (1998) suggests that knowledge acts to economise on the use of physical resources in three distinct ways. The embedding of knowledge within physical resources such as mass produced products thus acting to regulate and control the processes by which they are created and produced; the organisation of physical resources through the embedding of knowledge as information within documents; and lastly, by enhancing the understanding of the agents that interact with those physical resources. In effect this last way reflects the importance of learning within organisations: ‘In contrast to physical assets, knowledge assets would in theory last for ever. Farming methods in certain parts of the world, for example, have remained unchanged for millennia, being handed down from one generation to another in the form of a tradition. By gliding from one physical substrate to another, a knowledge asset can prolong its existence indefinitely. The *economic* life of such an asset, however, is a function of how fast the knowledge base that sustains it is changing’ (Boisot, 1998, p.3).

Traditionally, neo-classical economics recognised only two factors of production (labour and capital). Romer (1986; 1990) however suggests that knowledge has become the third factor of production. In effect then, the knowledge economy acts as an extension to a manufacturing based economy. Tangible assets like capital and labour are not of less value, merely intangible assets (such as knowledge) have risen in perceived value. Where knowledge impacts upon this economic modelling is the pivotal role played in the process of production: 'Capitalism is undergoing an epochal transformation from a mass production system where the principle source of value was human labour to a new era of 'innovation-mediated production' where the principal component of value creation, productivity and economic growth is knowledge' (Florida and Kenney, 1991, p.637). This point is further emphasised by Houghton and Sheehan (2000, p.14): 'As information and knowledge add value to basic products manufacturing and services are becoming increasingly integrated into complex chains of *creation, production and distribution*. At the core of the economy are goods producing industries, linked into value chains which see inputs coming from knowledge-based business services and goods related construction and energy industries, and outputs going to goods related distribution service industries.'

Despite the relatively recent conception of the knowledge economy, the acknowledgement by Romer (1986; 1990) of the role of knowledge as an additional factor of production is in itself not new. Romer's work can be seen to build on that of Schumpeter (1934; 1939; 1942) which gave great importance to the role of innovation (and by implication knowledge) within economic models. Perhaps paradoxically, it is the fact that knowledge is intangible that has acted as one of the most important defining characteristics of the knowledge economy. As knowledge is intangible, it will in effect never deplete in the conventional sense. For organisations operating within the context of the new economy their challenges in managing knowledge relate less to its accumulation in the manner of a tangible resource, but rather to its application.

2.3 Forms and Types of Knowledge

One of the critical issues in any work concerning knowledge is in understanding what is meant by 'knowledge'. The attempt to understand what knowledge actually is has been the goal of philosophers since Plato and Aristotle. It is Plato's 'Theaetetus' which presents what is arguably the first recorded structured examination of the nature of knowledge. In the work, Socrates, Theodorus of Cyrene and Theaetetus try to define what knowledge is. Socrates raises the question which has effectively defined epistemology: 'Well, now we're at the heart of what puzzles me and what I cannot satisfactorily grasp on my own – what knowledge in fact is. Are we in a position to give an account of it' (Waterfield, 1987, p.20)? Plato presents three definitions of knowledge: knowledge as perception; knowledge as (true) belief; and lastly knowledge as justified true belief. This definition of knowledge was commonly used until Gettier's argument that knowledge was in fact not the same as justified true belief. (1963). Gettier proposes two scenarios in which despite the fact that a subject has a justified true belief, this true belief can not be considered as knowledge due to entailment from justified false beliefs. Although various responses to Gettier's argument have been made such as Nozik's (1981), the most commonly accepted epistemological approach is what has been referred to as a 'JTB+G' analysis which is in effect an analysis which is reliant on the discovery of an additional condition (a non-Gettier condition) which when added to the existing conditions of justification, truth and belief make the statement valid.

The ongoing debate concerning knowledge since the time of Plato can be seen to continue. Works such as Gettier's and its accompanying responses simply point to the difficulty in attempting to define something as amorphous as knowledge from a philosophical perspective. Yet despite this inability terms such as 'knowledge management' and 'the knowledge economy' are now commonplace which would seem to imply that in a societal sense something of the nature of knowledge is understood, even if an all-encompassing definition is not available or in fact possible. Indeed it has been questioned how helpful these types of definition are in the context of the current socio-economic environment. Referring to Alavi and Leidner (2001), Stenmark suggests that this critical concept should not be addressed from a philosophical perspective at all: 'the knowledge-based theory of the firm was never built on a universal truth of what knowledge really is but on a pragmatic interest in being able to manage organisational knowledge' (Stenmark, 2002, p.1). Although this may be an understandable argument, it is highly debatable in the long term how valuable this approach may be for both academics and practitioners alike. If, as Stenmark suggests, definitions of knowledge are not valid within this context, then how can discussion concerning managing knowledge as a resource even arise? In effect, before knowledge can be managed it is essential to understand (at least on some level) what it is.

One method often used in the attempt to define knowledge is to identify and understand the 'forms' or 'states' within which knowledge may exist, and also the various 'types' of knowledge. Although some of these have been identified within the introductory chapter, there are two forms of knowledge which can be seen to have a direct bearing upon the research. Many of the attempts at the classification of the forms of knowledge can be seen to be based heavily on the work of Polanyi (although Reber (1995, p.15) suggests that the work on 'tacit' knowledge may be traced back to work conducted in the 19th century). Critically, Polanyi proposes the concept of 'tacit knowledge' whereby knowledge, although possessed by an individual, cannot be articulated to others: 'I shall reconsider human knowledge by starting from the fact that we can know more than we can tell' (Polanyi, 1966, p.4). This seemingly simple sentence of Polanyi's belies a depth of understanding of the nature of knowledge. Polanyi is not suggesting that knowledge cannot be made explicit. Rather he is proposing that not all knowledge can be made explicit, and as such the knowledge an individual makes explicit is only a subset of their tacit knowledge.

This concept developed by Polanyi has become a fundamental element within the discipline of knowledge management. Much of the popularisation of this concept can be seen to be due to the work of Nonaka and Takeuchi (1995), however they define tacit and explicit knowledge differently from Polanyi: 'Tacit knowledge is personal, context-specific and therefore hard to formalize and communicate. Explicit or "codified" knowledge, on the other hand, refers to knowledge that is transmittable in formal, systematic language' (1995, p.59). Where Polanyi refers to tacit knowledge as knowledge that cannot be communicated, Nonaka and Takeuchi refer to it as knowledge that is difficult to communicate, and as knowledge which has not (as yet) been communicated.

Although this interpretation by Nonaka and Takeuchi can be seen to be commonly used, it is clearly not based on the work of Polanyi (despite the claims of Nonaka and Takeuchi) and as such provides misleading definitions of both. Tsoukas (2002) suggests that Nonaka and Takeuchi's definition of tacit knowledge 'ignores the essential ineffability of tacit knowledge, thus reducing it to what can be articulated' (2002, p.15). Some tacit knowledge then can be articulated, but this 'articulated knowledge' can only exist in the form of information, and does not necessarily give the recipient the capacity to act upon this 'knowledge'. Tsoukas goes on to state that 'Tacit and explicit knowledge are not the two ends of a continuum but the two sides of the same coin: even the most explicit kind of knowledge is underlain by tacit knowledge. Tacit knowledge consists of a set of particulars of which we are subsidiarily aware as we focus on something else' (2002, p.15). However despite this perspective, Tsoukas suggests that explicit knowledge can be used productively in relation to tacit knowledge: 'The ineffability of tacit knowledge does not mean that we cannot discuss the skilled performances in which we are involved. We can – indeed, should - discuss them provided we stop insisting on "converting" tacit knowledge and, instead, start recursively drawing our attention to how we draw each other's attention to things' (2002, p.15). In effect then Tsoukas suggests that conveying our tacit knowledge to others does not give them knowledge, it simply conveys to others what is known.

Pathirage, Amaratunga and Haigh (2007, p.115) state that 'the classification of tacit and explicit knowledge remains the most common and practical.' However, although this classification can be seen from the literature to be the most common, it is highly debatable whether it is the most practical due to the misuse of Polanyi's (1966) work on tacit knowledge by Nonaka and Takeuchi (1995), and the subsequent widespread adoption of their definitions. This issue is highlighted by Tsoukas. Referring to Nonaka and Takeuchi's 'Knowledge Creating Company', Tsoukas (2002, p.12) states that 'the preceding account of tacit knowledge has very little in common with that of Polanyi. Nonaka and Takeuchi assume that tacit knowledge is knowledge-not-yet-articulated: a set of rules incorporated in the activity an actor is involved in, which is a matter of time for him/her to first learn and then formulate.'

If Tsoukas' statement is to be accepted, then it follows that the terms tacit knowledge and explicit knowledge are insufficient in their own right to fully encapsulate knowledge in all its forms. Nickols (2000) attempts to address this issue in the flow diagram presented in Figure 1 below. Nickols (2000) suggests that implicit knowledge is knowledge that can be, but has yet to be articulated. Related to this perspective, Van Beveren (2002, pp.19-20) makes three propositions in relation to the relationships which exist between data, information and knowledge:

P1. Data and Information are only forms that are captured, transferred or stored outside the brain.

P2. Knowledge can only exist within individual human brains.

P3. Information is acquired through the sensors to be processed in the brain, and new knowledge is created from the processing of information.

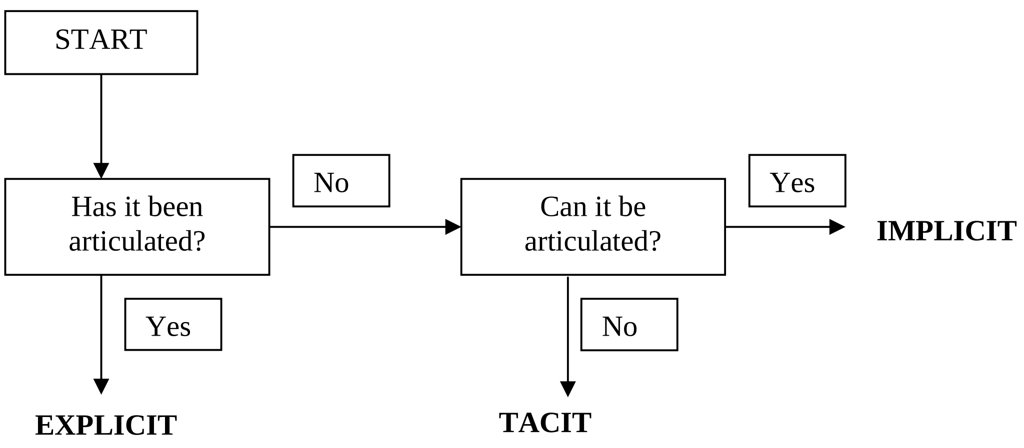

Figure 1: Explicit, Implicit and Tacit Knowledge [Source: Derived from Nickols (2000, p.18)]

Linking these propositions to Nickols' forms of knowledge identified above, explicit knowledge can be seen to be indistinguishable from information, and implicit knowledge must be conveyed in the form of information. This has implications for the knowledge-based processes (discussed below), and also in relation to technological innovation, the SECI process, which is (according to Nonaka and Takeuchi, 1995) reliant on the interactions between tacit and explicit knowledge.

A simplistic categorisation of knowledge types (as opposed to the forms of knowledge identified above) which has already been mentioned in the introductory chapter is that proposed by Lundvall and Johnson (1994): Know-what; Know-why; Know-how; and Know-who. This classification of knowledge types can be seen to be based on the various subjects of the knowledge. So, 'know-what' refers to knowledge about 'facts'. Lundvall (1996, p.5) suggests that this type of knowledge is in fact very similar to information: 'Here, knowledge is close to what is normally called information – it can be broken down into bits.' Know-why can be seen to be more related to the understanding of physical principles. Know-how is obviously skills-based knowledge or the knowledge required to perform a specific act or function. Lastly, know-who points to understanding who knows what. However Lundvall suggests that there is a deeper element to this type of knowledge as 'it involves the social capability to establish relationships to specialised groups in order to draw upon their expertise' (1996, p.6).

These different types of knowledge may be acquired in different ways, which points to the importance in understanding the different forms or states of knowledge as Polanyi (1966) presents them. Lundvall (1996) suggests that both know-what and know-why may be obtained through reading books and journals, or attending lectures or seminars. As such, both of these types of knowledge can be seen to be highly explicit, so much so in fact that Lundvall states that 'know-what and know-why can more easily be codified and transferred as information' (1996, p.6). From this it can be understood that certain types of knowledge can be seen to be very similar in form to information, and may be embedded within information sources (such as books or journals) in order to share them. Know-how however can be seen to be much more 'tacit' in nature, and may be acquired through 'learning through doing' processes such as apprenticeships for example. Lastly, know-who is socially acquired knowledge which can be seen to be gained through interacting within social networks. This type of knowledge is again highly tacit: 'Know-who is socially embedded knowledge which cannot easily be transferred through formal channels of information' (Lundvall, 1996, p.6).

This view of knowledge can also be seen to be echoed by Brown and Duguid: ‘The organizational knowledge that constitutes 'core-competency' is more than 'know-what' explicit knowledge which may be shared by several. A core competency requires the more elusive 'know-how' - the particular ability to put know-what into practice’ (1998, p. 91).

Alavi and Leidner (2001) provide a similar yet broader range of types of knowledge which they refer to as: declarative knowledge (know about); procedural knowledge (know how); and causal knowledge (know why). However they do not identify a type of knowledge relating to know who. Instead they introduce the concepts of (amongst others) conditional knowledge (know when) and relational knowledge (know with). These knowledge types identified by Alavi and Leidner (2001) and Lundvall and Johnson (1994) form part of the analytical template developed in partial fulfilment of the third research question (developed to examine the knowledge-based processes, and forms and types of knowledge within the innovation process) and applied in partial fulfilment of the fifth research question: What forms and types of knowledge are utilised within the innovation process?

This complex relationship between knowledge types and how knowledge may be transferred is neatly encapsulated by Wenger (1998) in the following statement: ‘If we believe, for instance, that knowledge consists of pieces of information explicitly stored in the brain, then it makes sense to package this information in well-designed units, to assemble prospective recipients of this information in a classroom where there are perfectly still and isolated from any distraction, and to deliver this information to them as succinctly and articulately as possible...But if we believe that information stored in explicit ways is only a small part of knowing, and that knowing involves primarily active participation in social communities, then the traditional format does not look so productive’ (Wenger, 1998, p.10).

Wenger (1998) thus provides an additional perspective on how knowledge may be understood in its relationship to information. A commonly used approach to explain this relationship is to view information and knowledge as part of a hierarchy of increasing complexity. This hierarchy (which is often referred to as the DIKW, or data information knowledge wisdom hierarchy) developed by Zeleny (1987) equates each level within this hierarchy to a knowledge type. Thus, data is equated to ‘know-nothing’, information to ‘know-what’, knowledge to ‘know-how’ and lastly wisdom to ‘know-why’. This does however seem to be an over-simplification of both the DIKW hierarchy as well as the knowledge types. Commonly, wisdom is omitted from this hierarchy and it is limited to data, information and knowledge alone. If, as Zeleny suggests, each level of this hierarchy may be related to a knowledge type, then in effect even data is a type of knowledge. Zeleny suggests that the hierarchy represents increasing levels of complexity. However Zeleny does not touch upon the relationship between this increasing complexity and the increasing levels of understanding which are implicit within this argument. This model is also used by Lazlo and Lazlo (2002) who consider an additional systemic dimension to the model:

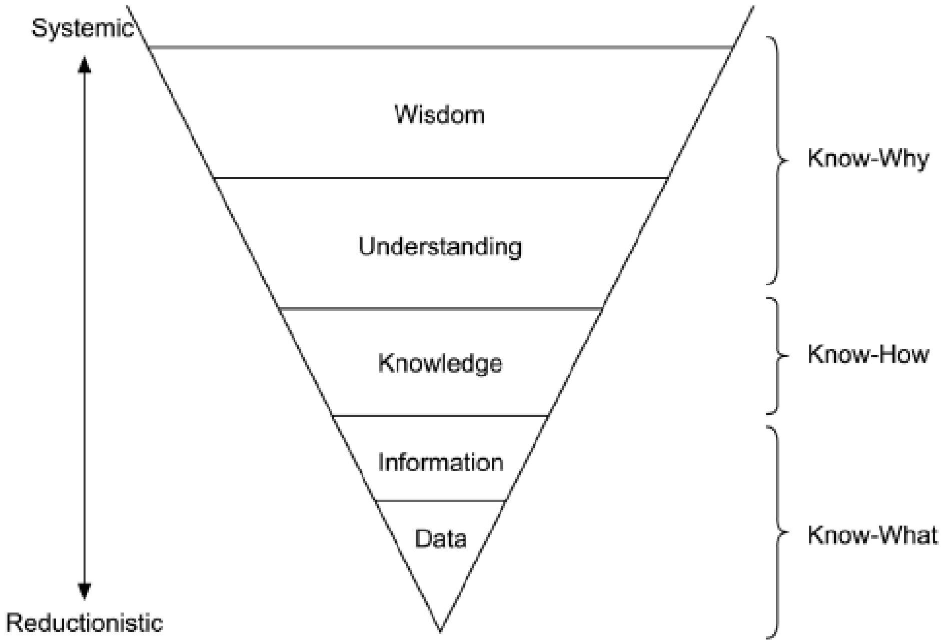

Figure 2: Pyramid of Meaning [Source: Derived from Lazlo and Lazlo (2002, p.405)]

This perspective can also be seen to support the methodological approach applied within this research, as Lazlo and Lazlo state that: ‘The distinction between reductionistic and systemic is correlated with the evolution of scientific knowledge that we mentioned earlier when describing the progression of business knowledge of the first, second, and third kinds...The quest for knowledge and understanding is a human enterprise that moves continually toward higher levels of complexity, less clear-cut answers, and more evolutionary possibilities. Inquiry in the social and human sciences is moving away from quantitative research and advancing toward qualitative, dialogue-based, and action-oriented forms of investigation’ (Lazlo and Lazlo, 2002, p.405).

It is evident from the literature that not only is it difficult to define knowledge per se, but also in attempting to define it in relation to other members of a hierarchy. What is lacking in these definitions is an explicit appreciation of the highly contextual nature of knowledge. What Zeleny (1987) seems to be implicitly indicating is the highly contextual and subjective nature of knowledge whereby what may appear to be simply data to one person may be information or knowledge to another. These relationships are presented more clearly through the use of examples by Boisot (1998). Boisot (whose work describing the interrelationships which exist between data, information and knowledge was presented in the introductory chapter) presents a simple (but not simplistic) set of definitions of these terms:

‘1. We take data to be simply a discernible difference between alternative states of a system. It is made up of low level energy that acts informationally rather than mechanically upon an observer.

2. Information is data that modifies expectations or the conditional readiness of an observer. The more those expectations are modified, the more informative the data is said to be.

3. Knowledge is the set of expectations that an observer holds with respect to an event. It is a disposition to act in a particular way that has to be inferred from behaviour rather than observed directly’ (Boisot, 1998, pp.19-20).

Boisot’s definitions can be seen to be useful in that not only do they describe data, information and knowledge in terms of their relationships, but they also explain how they differ. An additional benefit of the work of Boisot (1998) is that he contextualises the definition of knowledge within the knowledge economy: ‘In short, knowledge held by agents builds up the information structures latent in physical things, in documents, or in individual brains. Knowledge assets are those accumulations that yield a stream of useful services over time while economizing on the consumption of physical resources – i.e. minimizing the rate of entropy production’ (Boisot, 1998, p.13).

Boisot (1998) then brings the discussion back to Stenmark’s (2002) initial statement earlier in this section which suggests that without the context of the knowledge-based organisation a philosophical definition of knowledge is meaningless. However, these two perspectives are not mutually exclusive. One useful attempt at a definition of knowledge (if Gettier’s over-intellectualising is to be ignored) in relation to both the philosophical and socio-economic perspectives is that given by Sveiby (2002). In effect Sveiby (2002) provides a dual definition of knowledge drawing on both these perspectives and in addition identifies the various forms of knowledge associated with both of these perspectives. Sveiby (2002) defines knowledge as justified true belief and the capacity to act where justified true belief is ‘know what’ or know that’ which provides the raw material for deciding what to do (and includes facts, assumptions and values) and the capacity to act is ‘know how’ derived from resources such as procedures, rules, practical experiences, mental and physical abilities. Although Sveiby does not provide an exhaustive account of the forms and knowledge types within this definition, Sveiby's definition can be seen to be useful as it can be seen to acknowledge both different forms of knowledge (tacit and explicit) as well as some of the knowledge types, and it is for these reasons that this definition of knowledge has been adopted within this research.

2.4 Philosophical Perspectives on Knowledge

As stated in the first chapter the philosophical perspectives presented by postmodernism and post-structuralism also provide a valuable discussion concerning knowledge which can also be seen to be of particular relevance to this research. However prior to this there is a need to understand both what postmodernism and post-structuralism are, and also how they are relevant to this research.

Despite the clear acknowledgement of the importance of the role of postmodernism within the context of this research it is perhaps rather ironic that a definition of postmodernism as a concept is so elusive, as Harvey suggests: 'No one exactly agrees as to what is meant by the term, except, perhaps, that 'postmodernism' represents some kind of reaction to, or departure from 'modernism'. Since the meaning of modernism is also very confused, the reaction or departure known as 'postmodernism' is doubly so' (Harvey, 1990, p.7).

From Harvey's perspective, a definition of postmodernity is dependant on an understanding of modernity. Attempts can be made to understand these distinct yet inextricably linked concepts by examining their influence within creative fields such as literature and architecture, but also within economics, epistemology and social science research. However Jameson (1991) suggests that logic of attempting such definitions is fundamentally flawed: 'Whether…one can demonstrate the logical impossibility of any internally self-coherent theory of the postmodern…is a speculative question; its empirical answer is that none have so far appeared, all replicating within themselves a mimesis of their own title in the way in which they are parasitory on another system (most often on modernism itself), whose residual traces and unconsciously reproduced values and attitudes then become a precious index to the failure of a whole new culture to come to birth' (Jameson, 1991, p.xii).

The specific characteristics of both modernism and postmodernism can be seen to manifest themselves in a variety of different fields. Within the field of literature, Klages (2003) identifies a number of characteristics of modernist literature which can be seen to be relevant to this research. These include: an emphasis on impressionism and subjectivity in writing; an emphasis on how seeing (or reading or perception itself) takes place, rather than on what is perceived; a movement away from the apparent objectivity provided by omniscient third-person narrators, fixed narrative points of view, and clear-cut moral positions; and an emphasis on fragmented forms, discontinuous narratives, and random-seeming collages of different materials.

Although many of these concepts are also present in postmodern art and literature, Klages (2003) suggests that it is the way these concepts are viewed that distinguishes modernism from postmodernism: 'But…while postmodernism seems very much like modernism in these ways, it differs from modernism in its attitude toward a lot of these trends. Modernism, for example, tends to present a fragmented view of human subjectivity and history...but presents that fragmentation as something tragic, something to be lamented and mourned as a loss...Postmodernism, in contrast, doesn't lament the idea of fragmentation, provisionality, or incoherence, but rather celebrates that. The world is meaningless? Let's not pretend that art can make meaning then, let's just play with nonsense' (Klages, 2003). Klages seems to suggest then that it is less the content or structure of postmodern works which sets them apart from modern works, and more about their view of that which they present. As Homer (1997) suggests, postmodernism is fundamentally a playful concept. Postmodernism transcends the creative arts however, and is equally placed by Jameson as a concomitant of what he refers to as 'late capitalism' (an expression notably derided by Derrida): 'Each time I fall upon this expression 'late capitalism' in texts dealing with literature and philosophy, it is clear to me that a dogmatic or stereotyped statement has replaced analytical demonstration' (Derrida, 1987, p.254).

Harvey presents some defining characteristics of modernism which help to understand the opposing nature of postmodernity: 'Generally perceived as positivistic, technocentric, and rationalistic, universal modernism has been identified with the belief in linear progress, absolute truths, the rational planning of ideal social orders, and the standardization of knowledge and production' (Harvey, 1990, p.9). It is this standardised view of knowledge presented by modernism which is wholeheartedly rejected by postmodernism. Fundamentally, it is this change of philosophical perspectives which is sought to be acknowledged within the scope of this research.

Modernity on one hand takes a highly positivistic, structured view of knowledge in which only scientific knowledge is viewed as being of value (or where science and knowledge are in fact the same thing): 'The declared aim of modern science is to establish a strictly detached, objective knowledge. Any falling short of this ideal is accepted only as a temporary imperfection, which we must aim at eliminating. But suppose that tacit thought forms an indispensable part of all knowledge, then the ideal of eliminating all personal elements would, in effect, aim at the destruction of all knowledge. The ideal of exact science would turn out to be fundamentally misleading and possibly a source of devastating fallacies' (Polanyi, 1966, p.20).

Postmodernism on the other hand adopts an almost purely phenomenological perspective which encompasses another form of knowledge: narrative knowledge. 'Science has always been in conflict with narratives. Judged by the yardstick of science, the majority of them prove to be fables. But to the extent that science does not restrict itself to stating useful regularities and seeks the truth, it is obliged to legitimate the rules of its own game. It then produced a discourse of legitimation with respect to its own status, a discourse called philosophy' (Lyotard, 1984, p.xxiii).

Jameson suggests that the postmodern world is 'a more fully human world than the older one' (Jameson, 1991, p.ix), however once again a fundamental paradox of postmodernism is encountered as Lyotard (1984) suggests a move towards a society increasingly reliant on information systems and technology. How then can these seemingly opposing views be presented under the banner of a unifying theory? Lyotard may be suggesting that the technology may be used to bring together the tacit and explicit knowledge in a more meaningful way. The technology may be used to link individuals to other individuals, or to other sources of information.

Despite the number of paradoxes inherent in postmodernism and the seeming impossibility of definition, it is perhaps as Jameson (1991, p.ix) suggests, wrong to view these as somehow intrinsic failings: '…the theory seems necessarily imperfect or impure: in the present case, owing to the "contradiction" whereby Oliva's (or Lyotard's) perception of everything significant about the disappearance of master narratives has itself to be couched in narrative form.' So there are clearly difficulties in distinguishing postmodernism from modernism. Harvey suggests that a good place to start the identification of substantive differences between the two is by examining Hassan's (1985) table of schematic differences between modernism and postmodernism, an abbreviated version of which is provided below in Table 2.

The differences outlined by Hassan (1985) can be seen to cover a multitude of different disciplines illustrating the far reaching influences of both modernity and postmodernity in vastly diverse fields. Although a useful starting point, Harvey is quick to point out the danger of depicting such complex relationships as polar opposites. However they could be considered to be dialectics, each presenting a thesis (in the form of modernism) an antithesis (in the form of postmodernism), which may fit relatively neatly with Boje's (2001) questioning of Lyotard's (1984) utter rejection of grand narratives discussed below.

Clearly there are inherent difficulties in attempting to define postmodernism. Indeed Homer (1997) suggests that by its very nature, postmodernism is in fact impossible to define. Jameson (1991, p.6) goes further by suggesting that there is an inherent problem in trying to describe any, as he describes it 'totalizing dynamic': 'What happens is that the more powerful the vision of some increasingly total system or logic – the Foucault of the prisons book is the obvious example – the more powerless the reader comes to feel. Insofar as the theorist wins, therefore, by constructing an increasingly closed and terrifying machine, to that very degree he loses, since the critical capacity of his work is thereby paralyzed, and the impulses of negation and revolt, not to speak of those of social transformation, are increasingly perceived as vain and trivial in the face of the model itself.' Critically then, one of the key distinctions between modernism and postmodernism is the acceptance (and even welcoming) of the lack of unified meaning, a term which Lyotard entitled 'the death of grand narratives' (Lyotard, 1984, p.17). As Harvey suggests postmodernism may indeed be viewed as 'a legitimate reaction to the 'monotony' of universal modernism's vision of the world' (Harvey, 1990, p.9).

Modernism	Postmodernism
Form (conjunctive, closed)	Antiform (disjunctive,open)
Purpose	Play
Design	Chance
Hierarchy	Anarchy
Art object / finished work	Process / performance / happening
Distance	Participation
Creation / totalization / synthesis	Decreation / deconstruction / antithesis
Presence	Absence
Centring	Dispersal
Genre / boundary	Text / intertext
Semantics	Rhetoric
Paradigm	Syntagm
Metaphor	Metonymy
Selection	Combination
Root / depth	Rhizome / surface
Interpretation / reading	Against interpretation / misreading
Signified	Signifier
Lisible (readerly)	Scriptible (writerly)
Narrative / grande histoire	Anti-narrative / petite histoire
Master code	Idiolect

Table 2: Schematic of differences between modernism and postmodernism [Source: Derived from Hassan (1985, pp.123-4) in Harvey (1990, p.43)]

This instantly presents the most notable paradox of postmodernity. Postmodernity is by its very nature a grand narrative in itself, and thus by its own rejection of grand narratives negates its own existence. This is however an inherent danger in using this argument of logic to detract from the overall meaning (if indeed there is an overall meaning) of postmodernism as a reaction to modernism. Indeed, Boje (2001) suggests that Lyotard’s total rejection of all grand narratives is unwise: ‘Grand narratives of legitimation are not as obsolete as Lyotard asserts. There are more of them and they do not seem to fade away to be replaced by a ‘postmodern Condition’. I think it makes analytic sense to look at modern and postmodern theorists who have many nuanced analyses of enduring grand narratives’ (Boje, 2001, p.38).

In fact Jameson suggests that the grand narratives presented by Lyotard are not even narratives but are in fact ‘eschatalogical schemata’ (Jameson, 1991, p.xi), and that a more persuasive argument towards postmodernism (especially in the arts) is not the death of the grand narrative but the death of linear history: ‘in art, at least, the notion of progress and telos remained alive and well up to very recent times indeed, in its most authentic, least stupid and caricatural form, in which each genuinely new work unexpectedly but logically outtrumpted its predecessor (not “linear history” this, but rather Shklovsky’s “knight’s gambit,” the action at distance, the quantum leap to the undeveloped or underdeveloped square)’ (Jameson, 1991, p.xi).

The post-structuralist perspective (which can be seen to be closely related to the postmodernist perspective) relevant to this work focuses on two key theories. Firstly, the theory of deconstruction in relation to text emphasises (amongst a variety of other things) the multiple meanings which may be attributed to works from differing perspectives (Norris, 1982). Secondly Kristeva’s concept of intertextuality suggests the interrelated nature of all textual work in which each text is related both to other texts read by the reader, and also to the reader him or herself (1986). Kristeva proposes two axes: a horizontal axis which connects the author to the reader; and a vertical axis which connects the text itself to other texts: ‘The word’s status is thus defined horizontally (the word in the text belongs to both writing subject and addressee) as well as vertically (the word in the text is oriented towards an anterior or synchronic literary corpus)...each word (text) is an intersection of words (texts) where at least one other word (text) can be read...any text is constructed as a mosaic of quotations; any text is the absorption and transformation of another’ (Kristeva, 1986, p.37).

Related to this view is the work of Barthes in which the meaning of a text lies with the reader, rather than within the text itself: ‘Any text is a new tissue of past citations. Bits of code, formulae, rhythmic models, fragments of social languages, etc., pass into the text and are redistributed within it, for there is always language before and around the text. Intertextuality, the condition of any text whatsoever, cannot, of course, be reduced to a problem of sources or influences; the intertext is a general field of anonymous formulae whose origin can scarcely ever be located; of unconscious or automatic quotations, given without quotation marks’ (Barthes, 1981, p. 39).

Postmodernism and post-structuralism thus present philosophical perspectives which are critical to this research. Firstly, postmodernism challenges the dominant logic of scientific knowledge and presents narrative knowledge as a legitimised form of knowledge. Secondly, post-structuralism challenges the implicit structures of knowledge. These issues are discussed further in the next chapter as they pertain to the methodological approaches used within this research.

2.5 The Management of Knowledge

The characteristics of the knowledge economy identified above point to a more formal appreciation of the value of knowledge from a personal to an economic level. Given the development of the knowledge economy and its supporting infrastructure provided by ICTs, organisations in both the public and private sector are realising that they need to more formally attempt to manage the most valuable of corporate assets: knowledge. This realisation of both what the knowledge economy is, and the value placed on knowledge within an organisational context, has lead to the development of a new branch of management science: knowledge management.

Knowledge management has attracted considerable interest from both the private and public sectors, as well as the academic community as a range of methods to manage knowledge-based processes. As the subject can be seen to be derived from a range of subject areas including information systems, information science, human resource management, philosophy, sociology amongst others, one of the key difficulties when considering knowledge management in an organisational context has been to define the scope of the subject. Because of this, a range of different definitions of knowledge management have been proposed which have reflected this broad coverage of subjects. These can be seen to range from those which focus on the use of information technology to support the management of knowledge, to those more concerned with the human, behavioural and cultural elements. Thus, Skapinker (2002, p.1) defines knowledge management as: 'using the ideas and experience of employees, customers and suppliers to improve the organization's performance', Bukowitz and Williams (1999, p.2) posit that knowledge management is: 'the process by which the organization generates wealth from its intellectual or knowledge-based assets', and Wiig (1997, p.8) proposes that it is: 'the systematic, explicit, and deliberate building, renewal, and application of knowledge to maximize an enterprise's knowledge-related effectiveness and returns from its knowledge assets'.

Spender (2005, p.149) asserts that the definitions of knowledge management are not very important 'provided we do not stop theorizing before reaching a position that encompasses all three types of knowledge', which he suggests are knowledge-as-data, knowledge-as-meaning, and knowledge-as-practice. Spender goes on to propose that by encompassing these three types of knowledge, this moves towards a theory of knowledge that includes knowledge in the form of both assets and processes which may both be objective or subjective. This can be seen to further support the perspectives of Alavi and Leidner (2001), Lundvall and Johnson (1994), and Sveiby (2002), whose collective work forms the basis of the analytical template presented in the next chapter.

The definitions of knowledge management can be seen to be as varied as the numerous definitions of knowledge, however what these (and other) definitions do have in common is the organisational perspective placed on knowledge management. Knowledge management has not (generally) been seen as something specifically of benefit to individuals, but to groups of individuals instead. This is perhaps one of the reasons why a uniting definition of knowledge management has been so elusive. Different organisations are applying knowledge management in very different ways due in part to the intended focus of knowledge management initiatives, but also more generally to differences in organisational culture. Rowley (1999) suggests two approaches are used by authors in defining knowledge management: project-based definitions and process-based definitions.

For example, Davenport and Prusak (2000, p.44) provide a project-based definition of KM (knowledge management) which focuses on KM from a strategic perspective: ‘Knowledge management is concerned with the exploitation and development of the knowledge assets of an organisation with a view to furthering the organisation's objectives. The knowledge to be managed includes both explicit, documented knowledge, and tacit, subjective knowledge. Management entails all of those processes associated with the identification, sharing and creation of knowledge. This requires systems for the creation and maintenance of knowledge repositories, and to cultivate and facilitate the sharing of knowledge and organisational learning.’ However, a more common approach to defining knowledge management is by identifying the knowledge-based processes within an organisational context. The value of identifying these processes is difficult to ignore, and even Davenport and Prusak (2000) allude to these processes within their own project-based definition.

Spender (2005) goes further and suggests a range of methods used to define knowledge management. He states that some writers begin a definition of knowledge management by asserting the rise of the importance of knowledge as a source of competitive advantage, and this is an approach that has been used within this chapter. However this is not a definition in itself. Similarly Spender suggests that others identify knowledge as an asset, and contrast this with other more traditional and tangible organisational assets in order to emphasise that knowledge as an organisational asset must be managed in formal way in its own right.

However again, this is not a definition in its own right. More close to a definition Spender argues that a third approach used to define the field is to suggest that knowledge management is itself a process which uses information technology to manage information. This is clearly a limiting approach to a definition as not only does it emphasise the role of information technology over more 'human' factors, but it fails to acknowledge the differences between information and knowledge.

He goes on to suggest that the three approaches used to define knowledge management identified above differ according to the background of those seeking to define the field: 'Economists tend to the first, treating knowledge as the crucial or strategic organizational asset. Organizational theorists incline to the second, seeing knowledge as the outcome of some crucial knowing and learning organizational processes. Information technologists incline to the last, seeing collecting and moving useful data as crucial' (Spender, 1995, p.128 in: Little and Ray, 2005).

Significantly what the various definitions also point to is the development in the understanding of both academics and practitioners of what knowledge management is, and this can be clearly seen in the view of knowledge management from an iterative perspective. The changes in understanding reflect both the understanding of what knowledge management is capable of, as well as its limitations and failings. Despite its relative infancy a number of writers (notably McElroy, 2000; Skyrme, 2000; Koenig, 2002) suggest that knowledge management has gone through a number of iterations, what Firestone and McElroy suggest can be viewed as 'generations' of knowledge management (2002). Firestone and McElroy are not alone in this perspective. Koenig (2002) describes the development of the discipline almost from a perspective of technological determinism where information and communication technologies were essential to its initial development. Similarly Snowden suggests that the first generation of knowledge management (prior to 1995) related to the 'the appropriate structuring and flow of information to decision makers and the computerisation of major business applications leading to a technology enabled revolution dominated by the perceived efficiencies of process engineering' (2002, p.100). These perspectives on both knowledge and knowledge management can be seen to be rather limited and appear to be less to do with the management of knowledge than the management of information. In fact, Burnett and Smith (2003) posit that this first generation of knowledge management viewed knowledge as a form of complex information.

This, in Koenig's view, was followed by a second stage in the development of the discipline which focused on more human factors, and can be seen to have drawn on Nonaka and Takeuchi's work on the relationships between tacit and explicit knowledge (1995). Koenig (2002, p.21) proposes that the third and last stage of knowledge management is: 'the awareness of the importance of content—and, in particular, an awareness of the importance of the retrievability and therefore of the arrangement, description and structure of that content.'

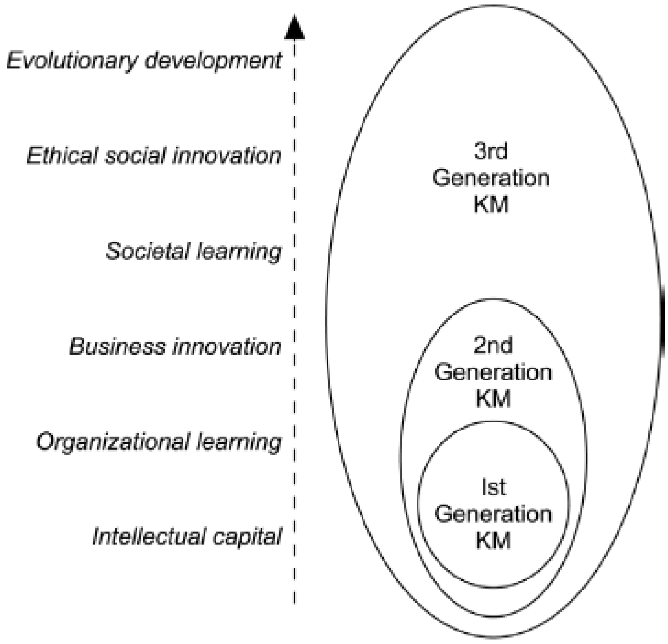

Figure 3: Generations of Knowledge Management [Source: Derived from Koenig (2002, pp.20-21)]

Although ICTs remain important in supporting knowledge management generally, it is the focus on the use of those technologies to support specific knowledge management processes which can be seen to be changing. As Firestone and McElroy (2002, p.6) suggest: '…current content management, taxonomy, and portal application concerns are about supporting knowledge coordination and transfer applications. They are not yet about supporting knowledge making, production and creation.'

The three generations of knowledge management act historically to identify the process areas focussed on within each generation. Koenig (2002) proposes that the first generation was technology driven, and focussed on the use of the internet to coordinate and share knowledge. The second generation expanded on the use of technology to include social and cultural factors: 'It might be described as the if-you-build-it-they-will-come-is-a-fallacy-stage...the recognition that "if you build it they will come." is a recipe that can easily lead to quick and embarrassing failure if human factors are not sufficiently taken into account' (Koenig, 2002, p.21).

The second generation then focussed heavily on the works of Nonaka and Takeuchi (1995) and Senge (1990). Nonaka and Takeuchi's work on tacit knowledge and Senge's work on learning organisations can be seen to emphasise the importance of acquiring new knowledge through learning, communicating that knowledge, and subsequently creating new knowledge. Lastly, Koenig suggests that the third generation of knowledge management emphasises the importance of structuring explicit knowledge to make it available to others who may need it. This last and most recent generation of KM then focuses on the storage of knowledge. The generations of knowledge management as suggested by Koenig (2002) can be seen to move the emphasis from the use of ICTs to support knowledge management, to more social and cultural factors, and subsequently back to factors once again relating to technology.

2.5.1 Knowledge-Based Processes

Each of the generations above can be seen to emphasise different knowledge-based processes existing within organisational contexts. By developing an understanding of what these processes are and how they affect organisations, a better understanding of knowledge management itself may be gained. As stated above, one of the most common methods for writers in the field to provide a definition has been to describe the discipline through the identification of the processes which it encompasses.

A number of authors have suggested the different knowledge-based processes. These processes can very often be seen as chronological steps within a system. Liebowitz (1999) identifies a number of process models proposed by different authors in the field which consist of varying numbers of steps. DiBella and Nevis (1998) suggest the simplest three phase model: acquire; disseminate; utilise. A number of authors suggest fours stage models. Wiig (1993), for example suggests that KM consists of a four stage process: creation and sourcing; compilation and transformation; dissemination; application and value realisation. McKenzie and van Winkelen (2004) propose a more complex seven stage model including the following stages: competing; deciding; learning; connecting; relating; monitoring; integrating.

Importantly, all these processes can be seen to treat knowledge as an organisational asset or resource, and as such allow for its formal management. The models (and the processes included within them) suggested by these authors can be seen have a number of common elements, and as such present knowledge management from a systemic perspective. Where they can be seen to vary is in their level of specificity. The application of these various theoretical models within practical organisational contexts has also been a popular topic for examination by both practitioners and academics alike. Specifically, many of these works have focussed on individual processes and how these processes may be made to operate efficiently through the use of supporting tools or technologies, rather than broader examinations of a number of different processes. However, it is an acknowledged challenge to try to separate out these processes as they are so closely related, an issue identified by Burnett el al (2004, p.9): 'The application or use made of the knowledge is the ultimate aim of any knowledge transfer process. The way in which the knowledge is applied is dependent on the form of the knowledge as well as the method by which the knowledge has been transferred. The subsequent codification or classification of knowledge, as with data and information, is a critical issue. The way in which knowledge is described will affect the way in which it is sought, and more importantly, who uses it.'

Clearly then, the various knowledge-based processes affect each other greatly, and as such there is an inherent danger in only examining one of these processes (such as knowledge transfer) without first having a clear understanding of how this process impacts on the others. From a practitioner's perspective, there is no one model which can be seen to be universally applicable within all organisational contexts. What can be suggested however is that a specific existing model used within an organisation (or one which it has developed for its own use) must reflect the processes which take place within that organisation, in the same way that the definitions used for knowledge and knowledge management must reflect the organisational context. Within the context of this research, a process-based model of knowledge-based processes is utilised which was developed and applied within a practical context within an organisation within the oil and gas industry (Burnett et al, 2004). This model (see Figure 4) does not present knowledge management as a linear process but rather as a collection of related processes, and is used as the basis of the analytical template described in Section 3.6.5.

The model itself drives the working definition of knowledge management which can be used in relation to this model. Knowledge management is a generic term for a range of processes including (but not limited to): knowledge acquisition and learning; knowledge transfer and dissemination; knowledge storage and maintenance; knowledge application and exploitation; measurement and valuation; and knowledge creation which collectively may enhance the effectiveness of a team, group, network or organisation. This model then can be seen to encapsulate a range of different knowledge-based processes:

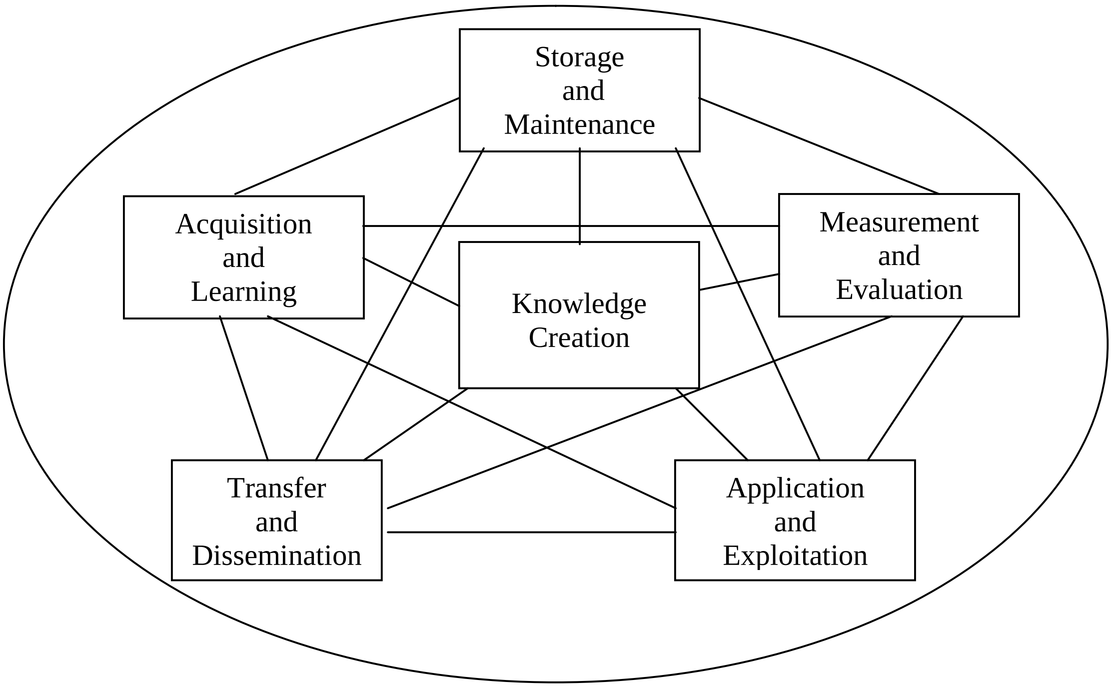

Figure 4: Knowledge Management Processes [Source: Derived from Burnett et al (2004, p.29)]

- How an organisation *acquires* knowledge and also *learns*;
- How an organisation *stores* its knowledge (both tacit and explicit), and ensures that it remains current through its *maintenance*;
- How it *transfers* knowledge between individuals, groups and departments internally, and also how it *disseminates* its knowledge outside the organisation;
- How it practically *applies* and *exploits* its knowledge through the production or improvement of its products and services, or through consultancy practices;
- How it places a *value* on its intellectual capital, and also determines how successful its knowledge management initiatives have been through *measurement*; and lastly
- How the organisation creates an environment whereby the *creation* of new knowledge is encouraged and facilitated.

Obviously as has been identified above, there can be seen to be an overlap and levels of integration between these processes. In effect then, it may be suggested that these are in fact knowledge-based ‘sub-processes’ which form part of an overarching knowledge management process, which when managed collectively help to formalise and (should consequently) improve the management of knowledge.

Within the context of this research six knowledge-based processes are identified and applied within the analytical template, based on the work of Burnett et al (2004). These are discussed in more detail below with particular reference to their importance and role within the innovation process.

2.5.1.1 Knowledge Acquisition and Learning

Both individuals and organisations may acquire both tacit and explicit knowledge in a variety of formal and informal ways and from a range of sources. Within the context of knowledge management, learning can be equated to the process of gaining or acquiring knowledge at a personal level (Polanyi, 1966). From an organisational perspective, the importance of learning cannot be overstated. Because of the complex nature of the current business environment organisations have to ensure that their knowledge is as current as possible. The more current the knowledge within an organisation, the better able that organisation is to make informed decisions. As Strata (1989, p.64) suggests: 'The rate at which organizations learn may become the only sustainable source of competitive advantage.' Learning is achieved as the individuals within an organisation acquire new knowledge and skills. Sun and Scott (2005) identify four levels of learning within and between organisations: individual; team-based learning; organisational and inter-organisational learning. This acknowledgement of the levels of learning which occur within and between organisations is important as it acts to link this process to the process of transferring knowledge.

Learning can also be seen to be closely related to change. Learning changes the understanding of individuals, and also change within the business context can be seen to require learning on the part of the players within that business context. These changes are however dependent on the 'absorptive capacity' of the learners (Jantunen, 2005) to acquire new knowledge. There are two different processes of organizational change that are associated with organisational learning: adaptive learning and generative learning. Defined by Hinchcliffe (1999, p.1336) as 'improvements within current paradigms', adaptive learning emphasises a form of reactive learning where players react and subsequently learn from changes in their environment. Adaptive learning or single-loop learning focuses on solving problems in the present without examining the appropriateness of current learning behaviours.

Adaptive organisations then focus on incremental improvements often based upon the past track record of success. Essentially, they do not question the fundamental assumptions underlying the existing ways of doing work. Generative learning on the other hand is the development and use of new organizational paradigms (Hinchcliffe, 1999) and can be seen to be a more strategic approach to learning. Indeed Osterberg (2004, p.156) states that: ‘To make generative learning in organizations possible, companies have a need for managers able to create a learning orientation while allowing network communication to take place in problem solving situations.’

Because of the highly complex nature of the business environment mentioned above, there can be seen to be a need for organisations to focus on generative learning or ‘double-loop learning’ (Argyris, 1977, p.113), and move away from simple adaptive learning. By moving towards an environment of generative learning, organisations are attempting to become ‘learning organisations’. According to Senge (1990, p.14) learning organisations are ‘…organizations where people continually expand their capacity to create the results they truly desire, where new and expansive patterns of thinking are nurtured, where collective aspiration is set free, and where people are continually learning to see the whole together.’ The rationale for this type of organisation is that in situations of rapid change (like those that characterise the current business environment) only those that are flexible, adaptive and productive will excel. For this to happen, Senge (1990, p.4) suggests that organisations need to ‘discover how to tap people’s commitment and capacity to learn at *all* levels’: the acquisition of knowledge and learning are not only limited to gaining knowledge or experience from within the organisation, but also from external sources. Leonard (1998, p.152) identifies a number of different types of organisation and individual from whom technological knowledge may be acquired:

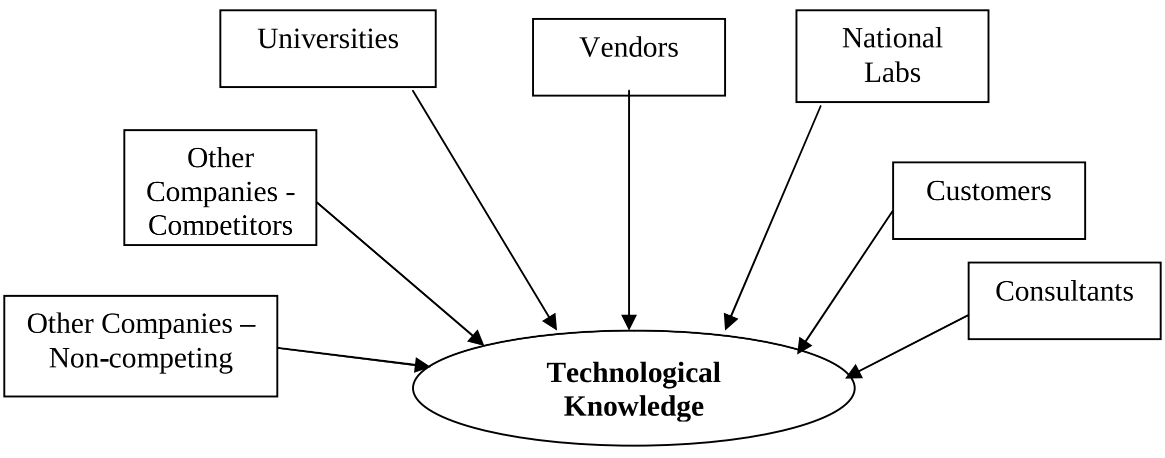

Figure 5: Sources of Technological Knowledge [Source: Leonard (1998, p.152)]

Additionally, Rothwell (1994) proposes a number of different mechanisms by which organisations may learn from both internal and external sources can be identified which can clearly be seen to relate to the innovation process:

Internal Learning	**External or Joint Internal/External Learning**
R, D&D – Learning by developing	Learning from/with suppliers
Learning by testing	Learning from/with lead users
Learning by making - production learning	Learning through horizontal partnerships
Learning by failing	Learning from/with the S&T infrastructure
Learning by using in vertically integrated companies	Learning from the literature
Cross-project learning	Learning from competitor's actions
	Learning through reverse engineering
	Learning from acquisitions or new personnel
	Learning through customer-based prototype trials
	Learning through servicing/fault finding

Table 3: Innovation as a process of knowledge accumulation [Source: Adopted from Rothwell (1994, p.27)]

Within the context of the technological innovation process, the acquisition of knowledge through learning is a key element for all groups of actors involved in this process. However, Rothwell (1994) does not go so far as to identify the forms and types of knowledge acquired by each group of actors (technology providers, enablers and end users), and this is an issue addressed within the scope of this research.

2.5.1.2 Knowledge Transfer and Dissemination

Closely related to the process of knowledge acquisition is the process of transferring knowledge. Of all the knowledge-based processes, knowledge transfer has perhaps received the most attention from both academics and practitioners alike, and can be seen to be a critical element of the innovation process itself. Organisations have begun to appreciate that they need to address not only the technological factors but also a range of cultural factors which impinge on their ability to transfer knowledge both internally and externally. Like the process of knowledge acquisition identified above, knowledge transfer may occur between individuals, teams and also between organisations.

Much of the literature relating to knowledge transfer can be seen to relate to the transfer of knowledge between individuals and teams (e.g. Dixon, 2000). This may be due to the scale of knowledge sharing at an organisational level which is either reliant on the transfer of tacit knowledge between individuals, knowledge which is then incorporated in a more explicit form within an organisation's knowledge-base and thus is really individual knowledge transfer, or where large quantities of 'knowledge' are being shared between organisations, the knowledge transferred is actually data or information. A key work in this field is Dixon's 'Common Knowledge' (2000). In it, Dixon identifies five different types of knowledge transfer at either a team or organisational level: serial transfer; near transfer; far transfer; strategic transfer; and expert transfer.

With specific reference to the innovation process, research has concentrated on types of linkage between specific kinds of organisation and also on the types of mechanisms designed to promote these linkages, or knowledge transfer support systems. These linkages have concentrated on the different types of organisation within the innovation process; however it is also possible to classify these organisations by their role within the innovation process, i.e., providers, enablers and users of innovation, and the transfer of knowledge between them. Azzone and Maccarone (1997, p.394) state that these three types of actor (which they classify as source, interface and recipient) can be shown to be the key stages in the reference framework for the analysis of different paths of knowledge transfer:

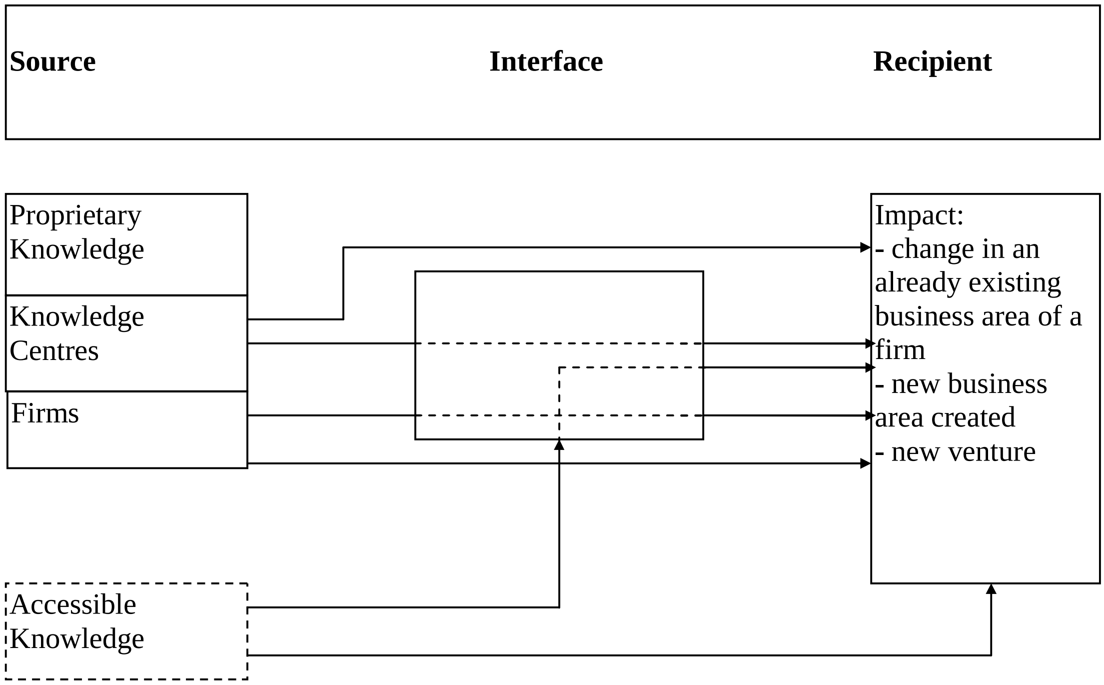

Figure 6: The Reference Framework [Source: Azzone and Maccarone (1997, p.394)]

Rather than identify specific organisational types of actors, Azzone and Maccarone (1997) classify the different providers of proprietary knowledge: knowledge centres and firms. These patterns of knowledge transfer can be seen to be the actual knowledge flows within the innovation process. Azzone and Maccarone (1997, pp.394-396) classify six types of knowledge transfer from this framework:

- Organisations who have sufficient in-house expertise to carry out research internally.
- Organisations who rely on an enabling organisation to search for some form of information necessary in order to successfully commercialise a technology.
- Direct transfer between firms occurs most notably within supplier-customer linkages.
- Direct transfer from a knowledge centre to a firm may occur through the acquisition of a licensing agreement, enabling the firm to develop or market a technology that has been originally developed within a university or research institute for example.
- Transfer from a firm to a supplier without direct involvement in the innovation process.
- Transfer from a knowledge centre to a user by means of an enabling organisation.

Within the innovation process, there can be seen to be individual reasons for player involvement in knowledge transfer. Perhaps the most discussed area of linkage is university/industry technology transfer. Hameri (1996) highlights the main incentives for science/industry collaboration:

- major technological advances and innovations originate from interaction between industry and the scientific community;
- ‘non-mission oriented’ research constitutes a fertile source of new innovations;
- technological breakthroughs require investments and the resources directed to fundamental research should also contribute to industrial competence;
- increased interaction and collaboration between diverse partners provide leverage to the creation of new ideas;
- transfer of technological knowledge is a two-way process where the information from provides solutions and new insight with an epistemic and an economic impact.

Bell (1993) argues that knowledge providers (such as research institutes, universities, etc) have gathered high levels of expertise (which may be understood to be tacit knowledge). Consequently, these organisations may derive income from the provision of training courses and consultancy services. Coupled to this fact is the current political view that there is a need general need for universities to improve linkage with industry to aid the innovation process and consequently help the economy.

Pertinent to the roles of the actors considered within this research, Azzone and Maccarone (1997, p.396) state that enabling organisations act to provide five support functions to aid the process of innovation: information; training; consultancy; qualification; and integration. One type of organisation who can be seen to carry out a number of these roles is governmental organisations. Rothwell (1994) highlights a number of potential roles for government as an enabling organisation:

- Government as a *direct* customer (public procurement)
- Government as a *proxy* customer (safety standards; environmental regulations)
- Government as a linkage creator between suppliers and users

Rothwell (1994) states that the most obvious role for government is as an end user/purchaser of knowledge. This may be at two levels, as a direct purchaser of knowledge by commissioning specific research from research organisations or universities (searching for a specific technological solution for a given need), or issuing calls for proposals for work to be conducted into an area of research (searching for a technological solution without a known specification). As a proxy customer, government can be seen to act on behalf of end users by ensuring quality control both for the finished technology, and also for the technology’s manufacturing process. This ensures that not only is the user provided with a quality product, but also to ensures that the technology has not in some way damaged the environment.

However, government also holds an important position as an enabling organisation. A vital function of government within the innovation process, which is not covered by Rothwell, is the role of government is providing an environment in which the innovation process can take place. Kirkland (1993, p.17) states: ‘There is widespread recognition that Britain should do more to exploit its scientific and technological inventions.’

Kirkland argues that poor linkages between universities and industry have been considered to be due to two causes: lack of ‘will’; and lack of information. Kirkland’s concepts can be seen to be essentially due to the cultural differences between the two types of organisation, and also the differences of the people within those organisations. Academics are not (generally) sufficiently interested in commercial exploitation and are more concerned with long- term research, while businesses are generally more interested in short-term approaches to problem solving and revenue generation (Kirkland, 1993).

The lack of information concept may be due to lack of expertise to ensure successful linkage: ‘Often, they have neither the expertise nor time to seek out appropriate industrial partners, and in any event lack the presentation skills to promote their case effectively. Companies, meanwhile, are said to lack knowledge of the support available for innovation, of how to seek out academic partners, and how to negotiate their way through complex academic procedures’ (Kirkland, 1993, p.19). However, Rothwell (1994) states that actual or potential users of knowledge transfer have active roles within the technology transfer process that may influence technological developments within the knowledge-producing organisation:

- Influencing emerging techno/economic trajectories (partnership in early-stage R&D)
- User as inventor (e.g. in scientific and medical instrumentation)
- Initiate search for a new technological solution to a radical new need (detailed specification unknown)
- Establishment of a precise set of user requirements (procurement role; detailed user specification)
- Source of solicited information on new/evolving needs (response to market research)
- Active collaboration during development (R&D partnership; prototype trials)
- Source of information on post-launch improvements (active or passive role)

Users then can be seen to have a number of different roles at different levels within the knowledge transfer process. At a strategic level, they act to direct research into specific areas of need/interest. At an operational level, the user may effectively act as a producer by producing a prototype invention, which is then developed by a manufacturing organisation. This linkage can be seen to be driven by a need of the user for a specific technology. Within this linkage the user who created the original knowledge benefits from licensing arrangements, and also from the development of a completed product. The manufacturer benefits from a development idea resulting in shorter development time, shorter time to market, and faster product diffusion within the market. If the user has not fully formulated a body of knowledge in the form of a prototype, they may search for expertise within a given area to develop a technology to solve a problem. This may range from having a full specification of a needed technology, to a broad but unstructured need for ‘something’. Linked to this is the users' role as information provider on market needs. This source of information can also continue through the development process, by user trialling of continuing iterations of a technology and also by providing feedback for future developments after it has reached the market.

Rothwell and Dodgson (1991) examine external linkages in small and medium-sized enterprises (SMEs). They state that due to the different type of business conducted by SMEs in comparison to larger organisations, this will necessarily impact on the types of linkages they have with other organisations. For example, SMEs generally fail to form linkages with large firms. The reason for this lack of ‘bonding’ can be seen to be due to a number of different factors: differing management structures; time horizons; lack of available capital. Generally this can be summed up by observing that there are cultural differences between these types of organisation. However, there are benefits for these linkages within the innovation process if they are developed and maintained. Rothwell (1991) also identified a number of types of linkage:

- Contracted out R&D
- Joint R&D ventures
- Marketing relationships
- Manufacturing relationships
- Links with educational establishments, other public sector bodies and research associations

Clearly then, the relationships between the different groups of actors within the innovation process are critical to the transfer of different types of knowledge which the literature shows is a key component in the development of a successful innovation. There can be seen to be a range of different activities undertaken individually or collaboratively by the different actors, and these activities appear to change over time. Similarly, the OECD acknowledge the importance of the diffusion (or transfer) of knowledge through a variety of agents: ‘One of the hallmarks of the knowledge-based economy is the recognition that the diffusion of knowledge is just as significant as its creation, leading to increased attention to “knowledge distribution networks” and “national systems of innovation”. These are the agents and structures which support the advance and use of knowledge in the economy and the linkages between them. They are crucial to the capacity of a country to diffuse innovations and to absorb and maximise the contribution of technology to production processes and product development’ (OECD, 1996, p.24). Once again, this issue can be seen to be pertinent to this research, as a critical function of an enabling organisation within the innovation process is to act as a networking agent.

Rothwell and Zegveld (1985, p.50) suggest that innovation may be viewed as an interactive process surrounding an organisation: ‘According to this model innovation is regarded as a logically sequential, though not necessarily continuous process, that can be subdivided into a series of functionally separate but interacting and interdependent stages. The overall pattern of innovation can be thought of as a complex net of communication paths, both inter-organisational and extra-organisational, linking together the various in-house functions and linking the firm to the broader scientific and technological community and to the marketplace. In other words the process of innovation represents the confluence of technological capabilities and market needs within the framework on the innovating firm.’ This argument that the innovation process can be considered as a complex net of communication paths is affirmed by Dorf and Worthington’s likening of the process to a type of game: ‘The effective commercialization of new technologies is less of a relay race where players hand off a baton to the next player than it is a basketball game where players pass the ball back and forth as they advance towards the goal’ (1987, p.2).

Clearly then this process has a definite beginning and end, but the interactions during the intermediate stages are more complex involving multiple interactions between actors to transfer knowledge. Closely related to the concept of innovation is technology transfer. Seaton and Cordey-Hayes (1993) argue that most research into technology transfer has concentrated on how inter-organisational networks have been used as tools for exploitation rather than examining how innovation may be achieved within organisations. They state that this focus on *inter*-organisational technology transfer (as opposed to *intra*-organisational technology transfer) has lead to a narrowing of the meaning of technology transfer to the transfer of technologies available for exploitation between organisations. However they go on to provide a broad definition of technology transfer as: ‘the process of promoting technical innovation through the transfer of idea, knowledge, devices and artefacts from leading edge companies, R&D organizations and academic research to more general and effective application in industry and commerce’ (1993, p.46).

Baron (1992, p.323) also provides a similarly broad definition of technology transfer as: ‘...any sharing of knowledge that ultimately results in a better commercial product (good or service), or a more efficient method of production.’ Essentially, therefore this process can be seen to be closely related, if not identical to the innovation process. However it is worth noting that in this definition, there is no emphasis on the sequentiality of the process. Once again the process has taken its title from a specific part of a more general process, in this case an action as opposed to a stage. Bonaccorsi and Piccaluga (1994) state that the technology transfer process can be seen to have four dimensions which can be seen to place emphasis on the role of knowledge:

- Time
- Appropriateness of the knowledge
- Tacitness of the knowledge
- Universality of the knowledge

These can be seen to be very similar to Azzone and Maccarone’s (1997, p.392) taxonomy of the different kinds of innovation. They classify innovation according to three dimensions: its degree of availability; the type of knowledge involved; and its degree of formalisation (see Figure 7 below).

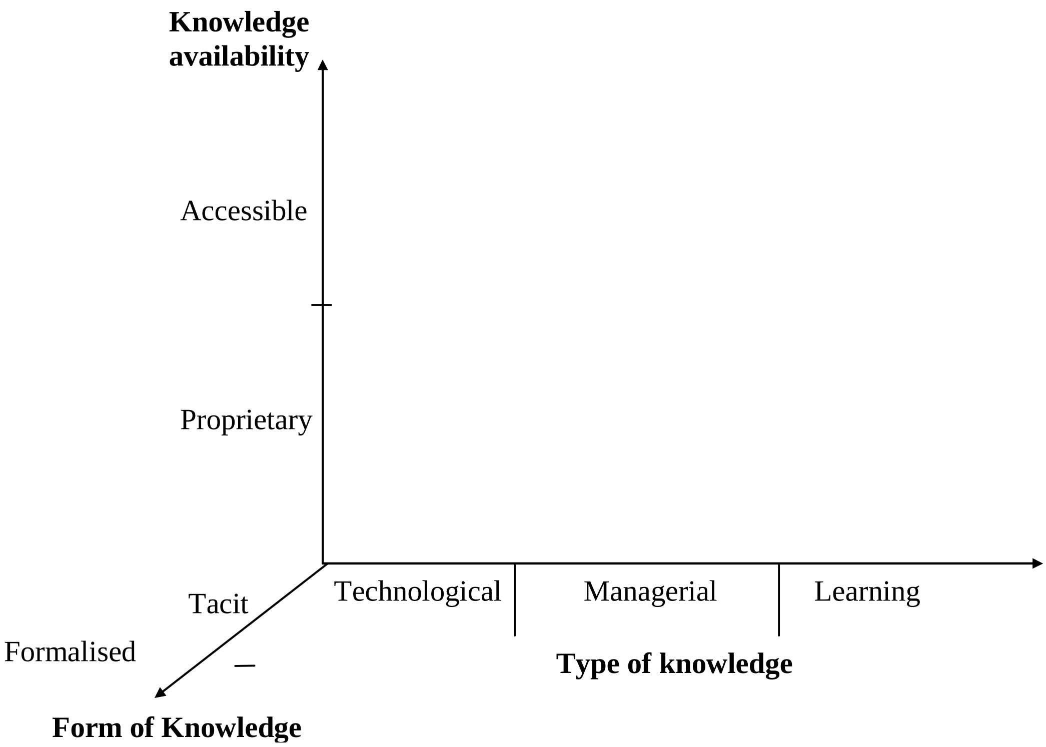

Figure 7: Dimensions of Innovation [Source: Azzone and Maccarone (1997, p.392)]

Appropriability or ‘Knowledge availability’ is essentially the ease by which the knowledge may be transferred. Azzone and Maccarone (1997, p.392) are more vague in their definition of availability, distinguishing only between ‘accessible know-how’ and ‘proprietary innovations’. This process is enabled by a number of supporting systems such as licensing, patenting, etc. Legislative arrangements are effective when the technology is relatively well advanced in its life cycle, however new discoveries are generally not covered quickly enough to protect them. Azzone and Maccarone (1997, p.393) argue that these restrictions are only effective when protecting proprietary knowledge, which requires ‘the direct involvement of the source of innovation’. ‘Know-how’ or understanding of a process is much more difficult to protect, and so consequently, Bonaccorsi and Piccaluga’s second point regarding the passing on of sensitive information can be seen to apply. Bonaccorsi and Piccaluga (1994) state that it is this level of formalisation which influences the support systems used to transfer knowledge. A formalised body of knowledge can be transferred using traditional information channels such as publications, conferences, meetings, etc. However, highly tacit knowledge obviously will be much more difficult (if not impossible) to transfer by these media.

Aside from these formal types of knowledge transfer, knowledge transfer within organisations often happens informally and as such may not require sophisticated technologies or formalised processes to support this. This informality however is often seen to ‘devalue’ the knowledge sharing process. Davenport and Prusak (2000) however suggest that organisations should not only acknowledge informal knowledge transfer, but actually place a high value upon it: ‘Spontaneous, unstructured knowledge transfer is vital to a firm’s success. Although the term “knowledge management” implies formalized transfer, one of its essential elements is developing specific strategies to encourage such spontaneous exchanges’ (2000, p.89). In this context then, both the culture and physical space of an organisation can impact upon an organisation’s ability to transfer knowledge. Davenport and Prusak go on to identify a range of cultural barriers (or frictions) to transferring knowledge which can be seen to be echoed by Pawar and Sharifi (2002). Pawar and Sharifi (2002) identified a number of cultural barriers which can be seen to impact on good knowledge management practice, and particularly knowledge transfer.

BARRIER	SUMMARY	SUGGESTED SOLUTION
ACCURACY/ RELIABILITY OF KNOWLEDGE	♦ When knowledge is shared people do not know how reliable it is. ♦ People also worry about the completeness and sincerity of knowledge passed to them.	♦ This aspect is fully based on trust and is hence a very delicate issue. ♦ Trust implies long relationships or having good references to rely on. ♦ Trust seems to be a major critical issue
FEAR OF LOSING COMPANY STABILITY/ MARKET POSITION	♦ It is felt that “giving away information” through knowledge sharing may result in loss of company stability or market position ♦ By sharing knowledge it is thought that it could result in companies having the same abilities and knowledge – resulting in companies losing their competitive advantage	♦ A change of mindset must occur to overcome these barriers. ♦ Companies must have a clear vision of who to share information with and what to share. ♦ Education that sharing information between companies can highlight companies core competencies which can lead to more business not less.
PROTECTION OF PROPRIETARY KNOWLEDGE	♦ Fear that ones ideas will be stolen by another and passed off as their own. ♦ Such information is what people feel they get promoted/pay increases on etc.	♦ Mechanisms must be found to guarantee that track back an idea to its originator. ♦ A change of mindset is required
MAINTENANCE OF COMMUNICATION CHANNELS	♦ By opening up internal structures for public scrutiny, the customers or suppliers may approach wrong people within the company for queries – therefore maybe not the best person.	♦ Must maintain the balance between openness towards the customer and keeping the discipline in performing certain processes.

Table 4: Barriers to Knowledge Transfer [Source: Derived from Pawar and Sharifi (2002, pp.91-96)]

Although a useful guide to practitioners, the actual methods by which these 'solutions' may be achieved are not addressed within it. In part this may be a tacit acknowledgement that solutions to cultural issues are more challenging to reach than more technological problems. In a broader context however, this is also a reflection of the highly context specific nature of knowledge management, where generic solutions to problems specific to the culture of organisations are not available, or in fact cannot be developed, a view which is echoed by Guzman and Wilson (2005).

From the above discussion, there can be seen to be a range of different approaches to the issue of knowledge transfer drawing on both practical and theoretical perspectives. While the literature reveals that both the processes by which knowledge may be transferred and the issues which affect the successful transfer of knowledge are well identified, there can clearly be seen to be a need to examine the issue of knowledge transfer more deeply within a variety of different contexts. This research then examines the transfer of knowledge (in addition to the other knowledge-based processes identified above) within one specific context, and as such aims to contribute to the understanding of this critical process. The research contributes to the field of knowledge transfer by examining the forms and types of knowledge transferred between the actors within the technological innovation process, and the barriers and enablers to those transfers.

2.5.1.3 Knowledge Storage and Maintenance

The storage and maintenance of knowledge would appear to be the most straightforward of all the knowledge processes. Storage arguably provides the foundation to a number (if not all) of the knowledge-based processes identified above. Once knowledge has been stored in a meaningful form it may be shared, used and valued. However, there is a fundamental implication here which is that knowledge can be codified and stored at all. The use of information and communication technologies lends itself to supporting the view of knowledge as a thing which can be acquired, transferred, duplicated and deleted in much the same was as information can be, and it is here that the key problem arises. How can knowledge be distinguished from information, and more specifically how can explicit knowledge be distinguished from information?

By definition, the storage of knowledge within an organisational context can only relate to the explicit knowledge resources: 'If one believes that tacit knowledge needs to be formalized and made explicit to share it more easily, then an important part of the knowledge management process is to capture and store this knowledge into knowledge repositories' (Liebowitz, 1999, p.19). However the debate as to whether it is actually knowledge itself that is stored rather than information still exists. Hall (2006, p.117) in his consideration of the codification of knowledge (which can be seen to be part of the process of storing knowledge) neatly circumvents this debate: 'Nevertheless, a fundamental aspect of how we communicate our knowledge depends upon information flowing between people, and as such, the role and nature of codification within this process remains an important topic for research in organizations.'

The storage of knowledge can be seen to be inextricably linked with the process of knowledge acquisition or capture, as it is only when knowledge (either explicit or tacit) has been acquired that it can be stored. Liebowitz (1999) identifies a number of 'techniques' which may be used to store knowledge: The knowledge attic technique where 'knowledge is contributed by employees in a passive way, and passive analysis and dissemination are applied whereby no entity analyzes the knowledge to disseminate to appropriate individuals in the organisation who would benefit from its use'; the knowledge sponge technique which involves active collection but passive analysis and dissemination; the knowledge publisher technique which is passive collection but active analysis and dissemination; and the knowledge pump technique which allows for active collection, analysis, and dissemination (Liebowitz, 1999, pp.29-30).

A vital element within any technique used to store knowledge is the structuring of that knowledge to allow for its subsequent retrieval. This is an issue which has already been acknowledged in relation to information: 'Information is only valuable to the extent that it is structured. Because of a lack of structure in the creation, distribution and reception of information, the information often does not arrive where it is needed and, therefore, is useless' (Koniger and Janowitz, 1995, p.6 in: Rowley, 2000). Arguably one of the greatest challenges in the storage of knowledge has been to present that knowledge in a form which renders it available to anyone who may need it. Davenport and Prusak (2000, p.68) suggest that a paradox exists in the attempt to codify knowledge: 'The primary difficulty encountered in codification work is the question of how to codify knowledge without losing its distinctive properties and turning it into less vibrant information or data. In other words, some structure for knowledge is necessary, but too much kills it.'

They suggest four basic principles that practitioners should adhere to in order to successfully codify knowledge:

- Managers must decide what business goals the codified knowledge will serve (got example, firms whose strategic intent involves getting closer to the customer may choose to codify customer knowledge).
- Managers must be able to identify knowledge existing in various forms appropriate to reaching those goals.
- Knowledge managers must evaluate knowledge for usefulness and appropriateness for codification
- Codifiers must identify an appropriate medium for codification and distribution

(Davenport and Prusak, 2000, pp.68-87)

Similarly, Rowley and Farrow (2000, p.219) state that there are three guiding principles which have shaped the development of the organisation of knowledge: communities, user orientation and standardisation: ‘The three principles that emerge from this evolutionary process are:
(1) Knowledge needs to be organised for communities.
(2) In designing tools to support the organisation of knowledge, the guiding principle must be that of user orientation and predominant usage.
(3) Standardisation and networking provide infrastructures, which facilitate effective and efficient access to information and documents.’

In relation to communities, Rowley and Farrow (2000, p.220) argue that ‘in the struggle for establishment and survival it is easy to forget that the characteristics of communities define the not only information and services that they need, or will accept, but also the way in which that information needs to be organised.’ Rowley and Farrow clearly goes further in their consideration of the principles of knowledge organisation than Davenport and Prusak (2000), and their perspective on this subject can be seen to be more focussed on the perspectives of the users of the information or knowledge than the managers of that knowledge. However, Davenport and Prusak’s principles are not without merit as they are a reminder that any knowledge stored within an organisation must fulfil a purpose. Moreover, knowledge that is no longer valid can be seen to be positively detrimental to an organisation if it is used as the basis of a decision making process. As Rowley and Farrow state: ‘From a user's perspective this is probably the first era in which it has become more necessary to discard knowledge, than to hoard it’ (2000, p.221).

Rowley and Farrow (2000) go beyond simply providing guiding principles and specifically identifies three key stages in the organisation of knowledge which are clearly underpinned by storage: selection and evaluation; organisation; and de-selection and weeding. Although the stages can be seen to be derived from a more traditional information management perspective, Rowley and Farrow (2000) also identify three principles associated with the organisation of knowledge which are more closely related to knowledge management per se:

- ‘Knowledge needs to be organised for communities.
- In designing tools to support the organisation of knowledge, the guiding principle must be that of user orientation and predominant usage.
- Standardisation and networking provide infrastructures, which facilitate effective and efficient access to information and documents’ (Rowley and Farrow, 2000, p.222).

As stated above the structuring, storing and maintenance of knowledge is presented as a cornerstone of organisational management within the context of the knowledge economy as it is only once this resource has been stored that it may subsequently be used. However, this issue returns the debate to Polanyi’s discussion concerning tacit and explicit knowledge. Polanyi (1966) implies that only a small part of an individual’s tacit knowledge may be made explicit, and it is only when it is made explicit that it may be stored. However, an examination of the literature reveals that much of the work in this area has focussed purely on the storage of explicit knowledge, and has to a large extent ignored the issue of knowledge stored tacitly within individuals themselves. This may in part be due to the difficulties acknowledge above in differentiating explicit knowledge from information, and it echoes Stenmark’s (2002) sentiments that such debates merely provide a philosophical barrier to engagement with these practical issues.

In relation to this research and the relationship between knowledge and innovation, Scharmer (in von Krogh et al, 2000, p.44) provides a useful perspective on this issue. Scharmer identifies different types of explicit knowledge and their presentation in the form of information within an organisational context: ‘Examples of this kind of knowledge are a balance sheet (know-what), accounting rules (know-how), a report based on activity-based-costing (know-why), and the mission statement of a company (know-for). In all these examples, knowledge is conveyed in the same structure: it is presented as a piece of information that is separate from the practice or reality it denotes.’ Scharmer suggests that the real issue in relation to the forms of knowledge is not to get embroiled in a philosophical discussion, but instead to consider the role of this resource in the organisation: ‘The challenge…is related to relevance…: how do these types of explicit knowledge relate and contribute to the capacity to innovate and enhance creating value?' (Scharmer in: von Krogh et al, 2000, p.44).

2.5.1.4 Knowledge Application and Exploitation

This concept of the application of knowledge can be seen to be supported by Amidon's definition of knowledge innovation: 'the creation, evolution, exchange and application of new ideas into marketable goods and services for the excellence of an enterprise, the vitality of a nation's economy and the advancement of society as a whole' (Amidon, 1997, p.7). In relation to the development (or not) of technological innovations, Leonard (1998, p.92) suggests that there is one single underlying cause for the demise of any new product: 'the quite understandable but simplistic assumption that physical installation was the sole project objective and criterion for success.' The successful development of new tools or technologies then can be seen to be dependent on the application of knowledge (from a range of sources) within the process. This (as Leonard suggests) does not only include technological and scientific knowledge, but other bodies of knowledge such as knowledge of the business and contextual environments.

The link between innovation and knowledge application is perhaps most apparent during the prototyping stage of product development: 'Experimental activities draw upon core technological capabilities, but more important, they create new ones' Leonard (1998, p.134). The application of knowledge within the innovation process not only leads to the development of new product or services for an organisation, but also develops new methods of working, problem solving, etc. Prototyping also relies on an appropriate organisational environment and culture (very similar if not indistinguishable from knowledge creation) where by individuals can experiment with new approaches to production, or new products themselves. Leonard (1998) suggests that experimentation and prototyping create two kinds of new capabilities. Firstly, it acts to broaden the range of technological products and/or services which a company may offer. Secondly, the very process of experimentation leads to the development of a capability in its own right.

The concept of the application of knowledge in its own right emphasises the close relationship between the various knowledge-based processes which collectively form the discipline of knowledge management. Pertinent to this research there can be seen to be very close relationships between the creation of knowledge and its subsequent application within the context of the innovation process, which is discussed in more detail below. This research also identifies the forms and types of knowledge applied by the actors within the innovation process.

2.5.1.5 Knowledge Creation

The process or processes by which organisations create knowledge has become a subject which has been carefully covered by a range of writers in the field, and can be seen to be closely bound up with the concepts of both the application of knowledge which is addressed above and the process of innovation generally. Importantly, Leonard's 'Wellsprings of Knowledge' (1998), Rogers' 'Diffusion of Innovations' (1995) and Nonaka and Takeuchi's oft-cited 'Knowledge-Creating Company' (1995) have become critical texts within this area.

Nonaka and Takeuchi propose that it is the ability of organisations to innovate which determines if they are successful or not. As part of this process of innovation, they identify the importance of the organisation in creating knowledge and information: 'When organizations innovate, they do not simply process information, from the outside in, in order to solve existing problems and adapt to a changing environment. They actually create new knowledge and information, from the inside out, in order to redefine both problems and solutions and, in the process, to re-create their environment' (Nonaka and Takeuchi, 1995, p.56). This issue is important as it points to both to the relationships which exist between individuals and organisations and also the need for knowledge to change form if it is to move between individuals, and from an individual level to an organisational level.

Nonaka and Takeuchi (see Figure 8 below) suggest that knowledge may be created through the processes of converting knowledge into different states: from tacit knowledge to tacit knowledge through the process of socialisation; from tacit knowledge to explicit knowledge through externalisation; from explicit knowledge to explicit knowledge though combination; and lastly from explicit knowledge back to tacit knowledge through the process of internalisation (1995, p.62). However as they go on to note, it is not the organisations themselves that are the creators of knowledge: 'Tacit knowledge of individuals is the basis of organizational knowledge creation. The organization has to mobilize tacit knowledge created and accumulated at the individual level' (1995, p.72).

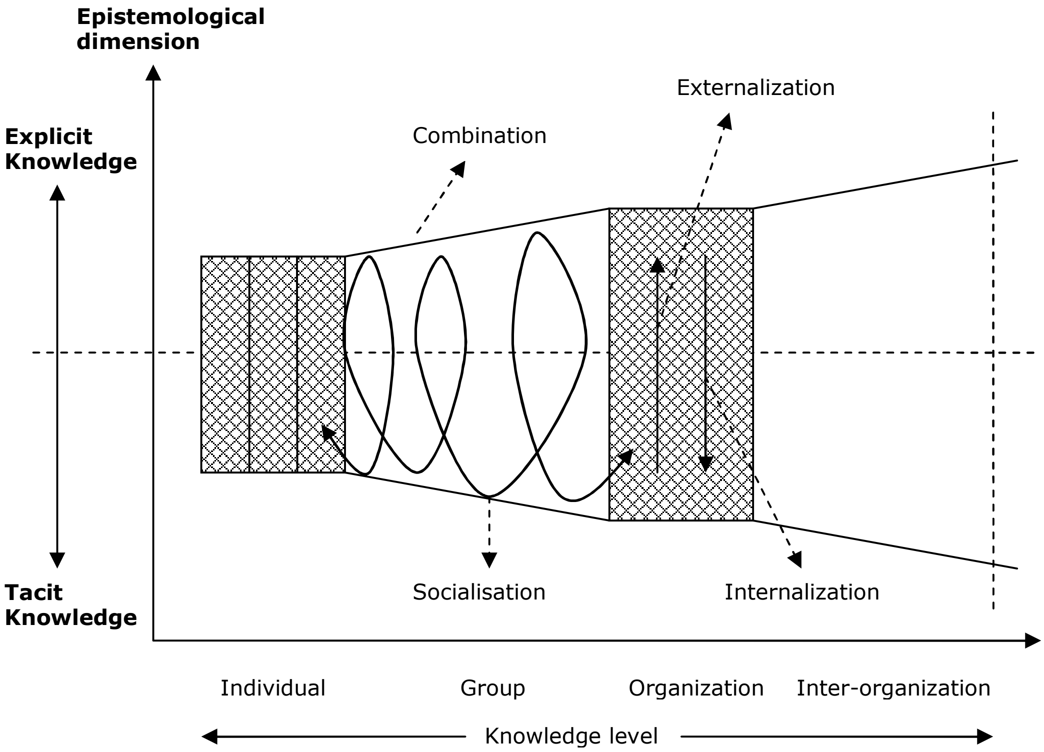

Figure 8: Spiral of organizational knowledge creation [Source: Derived from Nonaka and Takeuchi (1995, p.73)]

Nonaka and Takeuchi (1995) identify two dimensions of knowledge creation: an ontological dimension and an epistemological dimension. While the ontological dimension of knowledge creation is clearly related to the level within the organisational context at which the knowledge exists, the epistemological dimension can be seen to relate to two distinct forms of knowledge. In the epistemological dimension Nonaka and Takeuchi draw on Polanyi's concepts of tacit and explicit knowledge (Polanyi, 1966).

Although well established, this model is not without its critics. Indeed in Little and Ray's 'Managing Knowledge: An Essential Reader' alone four chapters highlight a number of flaws within it, most notably Nonaka and Takeuchi's alleged misinterpretation of Polanyi's work on tacit knowledge. As Cook and Brown state: 'Building on Polanyi, we argue that explicit and tacit are distinct forms of knowledge (i.e. neither is a variant of the other); that each does work the other cannot; and that one form cannot be made out of or changed into the other' (Cook and Brown, p.56, 1999, in: Little and Ray, 2005).

Other writers also acknowledge the close relationships between this process, and other knowledge-based processes. Indeed Davenport and Prusak refer to one ‘mode’ of knowledge generation (as they refer to it) as knowledge acquisition: ‘When we talk about knowledge generation, we mean the knowledge acquired by an organisation as well as that developed within it’ (2000, p.53). Similarly Quintas (2005, p.255) states that: ‘Innovation depends on a number of knowledge capabilities, as for example the capability to generate novelty and variety in the knowledge available to the organization, and the ability to apply knowledge in practical contexts.’ In relation to innovation then, the knowledge processes of both creating knowledge and applying that knowledge are critical.

Although clearly linked to knowledge and the innovation process, knowledge creation differs from the other knowledge management processes identified here in that despite the coverage it has received, the process of practically creating new knowledge is more challenging to formally manage. Spender (2005, p.147) goes further and suggests that: ‘...creativity itself cannot be part of a theory of knowledge management until we can either explain it with a causal (rational) model – a contradiction in terms – or, and this is the important novelty, showing something about how our imaginations are constrained by choices of context and boundaries.’ However, its importance to the overall innovation process is critical. Rubenstein (1994, p.653) emphasises the importance of knowledge creation in the process: ‘This early stage is critical to the whole R&D/I process, since it is the starting point for technical activities or projects which are intended to provide new and improved products, processes, services and know-how to support the technology base of the firm’s current and potential future activities.’

2.5.1.6 Knowledge Measurement and Valuation

The last knowledge-based process to be discussed in this chapter is the measurement and valuation of knowledge itself. The link between competitive advantage and knowledge is well documented, and has been discussed earlier within this chapter. Traditional differentiators such as land, labour and capital are now no longer deemed as valuable as intellectual capital and knowledge within the new economy. As a consequence, companies have sought to measure their ‘wealth’ in knowledge and intellectual capital in much the same way as they sought to measure their wealth in traditional capital.

Stewart's 'Intellectual Capital: The New Wealth of Organizations' was one of the first significant works to examine both why and how organisations could measure the value of their intellectual assets. Placing the work firmly within the context of the knowledge economy, Stewart (1998, p.xi) states that: 'Intellectual capital is intellectual material – knowledge, information, intellectual property, experience – that can be put to use to create wealth.' Naturally, Stewart is not the only writer to offer up a definition of intellectual capital. Klein and Prusak suggest that intellectual capital is: 'Intellectual material that has been formalized, captured and leveraged to produce a higher-valued asset' (1994, p.1).

Intellectual capital, intangible assets and knowledge assets have all been defined in a number of different (often contradictory) ways. The recent research into determining the 'value' of these assets seems to have driven the way in which they are described, and consequently restricts how they are considered (often in primarily quantitative approaches) and therefore often does not fully address the qualitative factors related to them.

Commonly, intellectual capital is defined as a combination of human capital, structural capital and customer capital. Brooking (1997) however suggests that that are four categories or components which comprise the intellectual capital of an organisation:

- Market assets including brands, customer loyalty and networks
- Intellectual Property Assets such as patents copyrights and software
- Human-centred assets such as qualifications skills and education
- Infrastructure Assets such as company culture, systems, and processes

These combine the human intellect within the organisation with both internal and external processes. Intellectual capital is not just the intelligence embedded within a company. It also includes the internal and external environments within which that intellect may be applied, and the processes used to apply it.

Boisot (1998, p.13) states that knowledge assets are 'those accumulations that yield a stream of useful services over time while economising on the consumption of physical resources.' Consequently, knowledge assets can be seen to add value to the physical resources (space, time and energy) of an organisation. The intellectual capital of an organisation will produce a company's knowledge assets. Intellectual capital is a measure of potential which has been translated into actual value in the form of knowledge assets.

The need for organisations to attempt to place value on intellectual capital is neatly emphasised by Sveiby: ‘Shares in Microsoft, the world’s largest computer software firm, changed hands at an average price of $70 during fiscal 1995 at a time when their so-called book value was just $7. In other words, for every $1 of recorded value the market saw $9 in additional value for which there was no corresponding record in Microsoft’s balance sheet’ (Sveiby, 1997, p.3).

A number of different techniques have been proposed which aid organisations in the identification and valuation of intangible assets such as the Balanced Scorecard, the Skandia Navigator, and the Intangible Assets Monitor. Each of these techniques neatly identifies the types of intangible assets within the organisational context. Not only do such techniques point to a need for organisations to place value on these assets, but more generally they imply a need for organisations to approach their management in more structured and strategic ways in order that value may be placed on the value of intellectual capital.

Once again emphasising the relationship between the different knowledge management processes, Klein suggests that: ‘To manage its intellectual capital more systematically, the firm must devise an agenda for transforming from an organization simply comprising knowledgeable individuals to a knowledge-focused organisation that stewards the creation and sharing of knowledge within and across internal business functions and that orchestrates the flow of know-how to and from external firms’ (Klein, 1998, p. 2).

Similarly Bontis (1998) suggests that the search for a ‘Holy Grail’ of intellectual capital valuation should be approached with great caution, and once again emphasises the need for an approach to knowledge management which focuses on the knowledge-based processes themselves: ‘Managers, analysts and researchers should also be wary of looking for a formula of intellectual capital. By definition, the tacitness of intellectual capital may not allow analysts to ever measure it using economic variables. A warning must be sent out to those accountants and financial analysts who are asking the question, “How much is my intellectual capital worth?” A formula may never exist. That is not to say that metric development is a waste of time. Longitudinal examination of metrics as well as benchmarking against industry norms can help managers in examining their own intellectual capital. In this case, examining the processes underlying intellectual capital development may be of more importance than ever finding out what it is all worth’ (Bontis, 1998, p.72). Bontis’ statement further underlines the need and importance of this research which examines these underlying processes leading to the development of new intellectual capital in the form of technological innovations.

2.6 The Innovation Process

2.6.1 Technological Knowledge in the Innovation Process

The OECD define innovation as ‘Knowledge that is in demand; an invention that has been introduced in the market and that has proven its relevance for the market economy’ (OECD, 2000, p.21). Within a Schumpeterian economy, innovation can be seen to be a key source of wealth generation: ‘In an e-conomy based on knowledge, information and intangibles (such as image and connections), innovation is the primordial function. Innovation depends on knowledge generation facilitated by open access to information’ (Castells, 2001, p.100). Castells then emphasises both the importance of knowledge (and knowledge-based processes) within innovation, and also the importance of knowledge to the economy as a whole.

For the purposes of this research, the definitions provided in the Oslo Manual (adopted by the OECD) are used. The OECD separate technological innovations into two main forms: technological product and process (TPP) innovations: ‘Technological product and process (TPP) innovations comprise implemented technologically new products and processes and significant technological improvements in products and processes. A TPP innovation has been implemented if it has been introduced on the market (product innovation) or used within a production process (process innovation). TPP innovations involve a series of scientific, technological, organisational, financial and commercial activities. The TPP innovating firm is one that has implemented technologically new or significantly technologically improved products or processes during the period under review’ (OECD/Eurostat, 1997, p. 32). This definition is provides the basis for all the legal innovation definitions within countries within the European Union.

Although a variety of links between knowledge and innovation have already been proposed in the first chapter which raises both knowledge and technological innovation as key concepts and earlier in this chapter which identifies the importance of innovation within the knowledge economy and the role of knowledge-based processes present within innovation, this section of the literature review further emphasises this relationship by highlighting the roles, types and forms of technological knowledge within the innovation process.

In addition to the generic types of knowledge discussed above, Gibbons and Johnson (1974) provide seminal work examining the contribution of scientific research and education (knowledge) to technological innovation. They provide a broad definition of scientific knowledge: 'Included in this are not only information contained in research papers and the forms of literature produced by scientists in universities, such as reviews, handbooks and textbooks, but also the information acquired through the network of professional relationships which the industrial scientist may have developed with colleagues and others in the university sector' (1974, p.223). These areas can clearly be seen to be closely related to both explicit and tacit forms of knowledge; however it is interesting to note that Gibbons and Johnson do not scruple to differentiate between information and knowledge. Rather, they consider information to be a specific type of knowledge. Gibbons and Johnson identify eight types of information which contribute to technological innovation:

- 'Existence or availability of equipment or materials with particular properties
- Properties, composition, characteristics of materials or components
- Test procedures and techniques
- Operating principles or rules, required specifications, technical limitations
- Location of information
- Theories, laws, general principles
- Design-based information
- Existence of specialist facilities or services' (1974, p.226)

Faulkner (1993) develops Gibbons and Johnson's (1974) concept of information types to include information, knowledge, artefacts and skills:

Knowledge of particular fields	scientific theory, engineering principles, properties etc
	'knowledge of knowledge'
Technical information	specifications and operating performance of products or components
	experimental or test procedures and results
Skills	specific skills such as programming, hardware design etc
	research or production competence
Artefacts	process or research instrumentation
	other intermediates (reagents etc)

Table 5: Scientific and Technological Inputs (STI) to Innovation [Source: Adapted from Faulkner (1993, p.5)]

Balazs (1996) goes further by stating that the knowledge utilised within the technological innovation is not only scientific or technical, but may also be business or management knowledge. He classifies these types of knowledge as follows:

- Knowledge relating to scientific research and teaching
- Skills relating to research
- Managing research
- Doing research
- Knowledge related to research contracts and business
- Knowledge related to research contracts and business
- Skills related to research contracts and business

These knowledge types relating to the innovation process identified by Balazs (1996) are in effect specific subsets of those provided by Alavi and Lieder (2001), and as such fall within the categories of knowledge types used within the analytical framework discussed in the next chapter. The variety of definitions and classifications discussed above can be seen to reflect both a deepening of a conceptual understanding of knowledge from a variety of perspectives within different contexts (such as the process of technological innovation), as well as the ongoing changes and developments with those contexts which may be seen to be attributable to the development of the knowledge economy, discussed earlier in this chapter.

Rothwell (1992) suggests that differing models of the innovation process have been adopted over time:

First generation: Technology-push	Simple linear sequential process
	Emphasis on R&D
	The market is a receptacle for the fruits of R&D
Second generation: Need-pull	Simple linear sequential process
	Emphasis on marketing
	The market is the source of ideas for directing R&D
	R&D has a reactive role
Third generation: Coupling model	Sequential, but with feedback loops
	Push or pull or push/pull combinations
	Emphasis on integration at the R&D/marketing interface
Fourth generation: Integrated model	Parallel development with integrated development teams
	Strong upstream supplier linkages
	Close coupling with leading edge customers
	Emphasis on integration between R&D and manufacturing (design for marketability)
	Horizontal collaboration (joint ventures etc.)
Fifth generation: systems integration and networking model	Fully integrated parallel development
	Use of expert systems and simulation modelling in R&D
	Strong linkages with leading-edge customers (customer focus at the forefront of strategy)
	Strategic integration with primary suppliers including co-development of new products and linked CAD systems
	Horizontal linkages: joint ventures; collaborative research groupings; collaborative marketing arrangements etc.
	Increased focus on quality and other non-price factors

Table 6: Generations of the Innovation Process [Source: Adapted from Rothwell (1994, pp.7-31)]

Nobelius (2004) elaborates on this model to suggest both the contexts within which these generations were placed, as well as their specific process characteristics:

R&D Generations	Context	Process Characteristics
First Generation	Black hole demand (1950 to mid-1960s)	R&D as ivory tower, technology-push oriented, seen as an overhead cost, having little or no interaction with the rest of the company or overall strategy. Focus on scientific breakthroughs.
Second Generation	Market shares battle (mid-1960s to early 1970s)	R&D as business, market-pull oriented, and strategy-driven from the business side, all under the umbrella of project management and the internal customer concept.
Third Generation	Rationalization efforts (mid-1970s to mid-1980s)	R&D as portfolio, moving away from individual projects view, and with linkages to both business and corporate strategies. Risk-reward and similar methods guide the overall investments.
Fourth Generation	Time-based struggle (early 1980s to mid-1990s)	R&D as integrative activity, learning from and with customers, moving away from a product focus to a total concept focus, where activities are conducted in parallel by cross-functional teams.
Fifth Generation	Systems integration (mid-1990s onward)	R&D as network, focussing on collaboration within a wider system – involving competitors, suppliers, distributors, etc. The ability to control product development speed is imperative, separating R from D.

Table 7: R&D Generations [Source: Adapted from Nobelius (2004, p.370)]

Campodall'Orto and Ghiglione (1996) argue that these models (and indeed models of R&D management) have been affected by changes in the market place since the early 1960s. Consequently, it can be seen that the models suggested by Rothwell (1994) have developed or changed as a continuing reaction and need to redress issues relating to the market. Where once a model was able successfully be used to transfer technologies, changes in commercial markets and also economic policy ensured that innovation models had a limited lifespan. It is possible therefore to attribute relatively accurately which models were used at which times.

The importance of the generations of R&D management is that they suggest an evolution of thought which has developed since the 1950s. As Nobelius (2004, p. 375) suggests: ‘It is important to realize that the notion of R&D generations is one way of communicating different management approaches under certain conditions and contexts’. From the preceding work within this chapter, one context within which the later models can be placed is the knowledge economy itself, and indeed this may be reflected in the acknowledgement of the importance of knowledge within the process as seen in the later models.

The first generation model is generally attributed to innovation in 1950s. During this period, it was considered that innovation was a linear process that could be followed in a straight line from invention, through development to the marketing of a new technology. Rothwell and Dodgson (1991) state that during this time, research and development policy within Europe was divided between science and industrial policies. Each policy focussed on a different area: science policy on education, university-based research and also research with government funded laboratories. Industrial policy focussed on more technically focussed education and training, and industrial development. There was however little or no interaction between the two sets of policy makers and so consequently, the rudimentary technology push model was seen to be in use, where products were developed regardless of user needs.

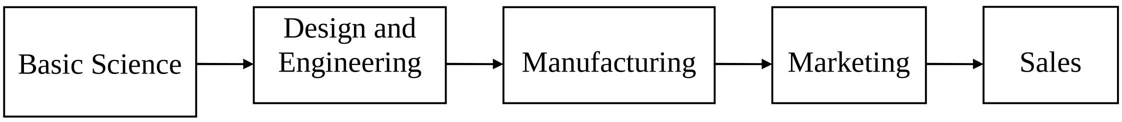

Figure 9: The First Generation Innovation Model (Technology Push) [Source: Rothwell (1994, p.8)]

The second generation model was used until the 1970s and was of a similar structure to the first generation model, but with the emphasis lying at the other end of the model with the marketing of technologies. This was a reactive model in contrast to the proactive first generation model. Rather than pouring products into the market place, this model used the market to provide guidance for areas of research and development.

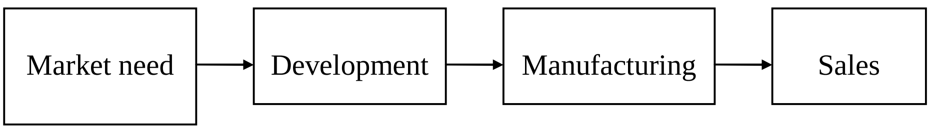

Figure 10: The Second Generation Innovation Model (Market Pull) [Source: Rothwell (1994, p.9)]

From the mid 1970s until the early 1980s a new policy of innovation, initially developed in the USA, led to a more complex models of innovation being adopted. This new policy trend was driven by an understanding than the innovation process was not, as had previously been assumed, a sequential linear process but a much more complicated process. Consequently, the environment surrounding the innovation process was enriched by different schemes and initiatives designed to catalyse and promote innovation, for example grants for innovation. Unlike the two previous models that swung between emphasis on the far ends on the innovation process, this model provided a much more balanced approach to innovation resulting from the integration of the theoretical R&D with application. This model was therefore developed by producing a theoretical framework of applied practice. Although still essentially linear in nature, the model placed a much higher emphasis on the interaction between the various stages within the process rather than the previous models that used a more ‘one way’ transfer of knowledge.

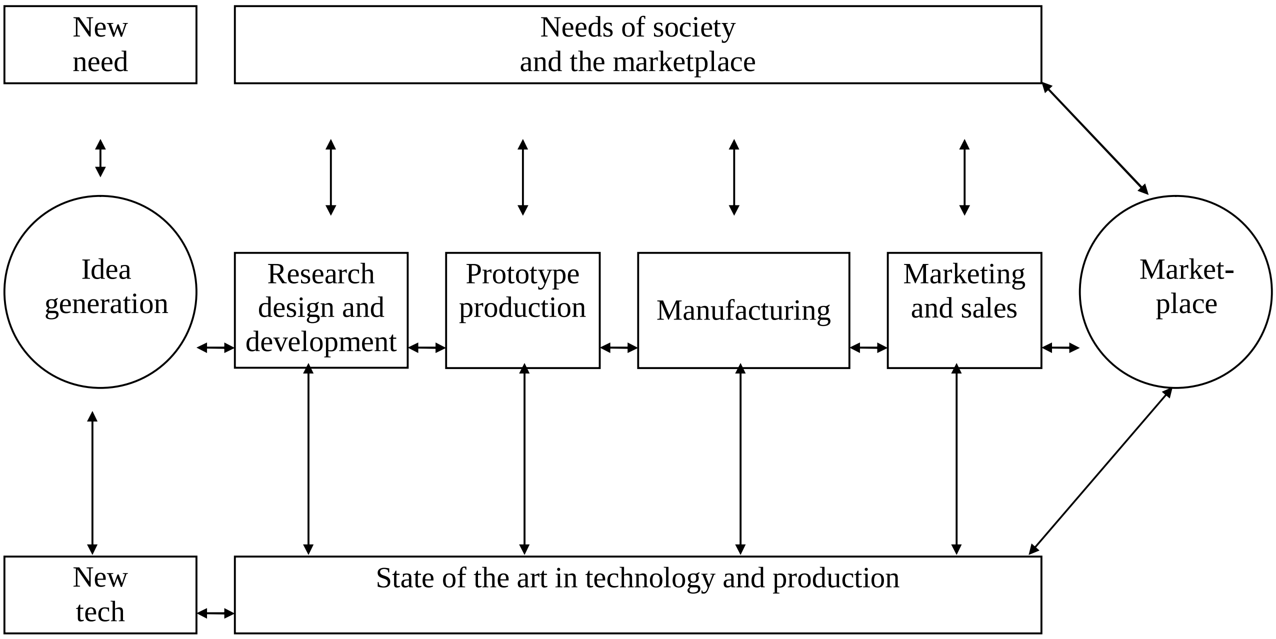

Figure 11: The Third Generation Process Model (The Coupling Model) [Source: Rothwell (1994, p.10)]

The integrated model of innovation used from the early 1980s to the mid 1990s moved beyond the simplistic sequential model of earlier models, and instead considered innovation as a number of parallel processes operated by integrated working groups. Like the Coupling model, this was again an attempt to produce a theorised version of actual working processes to produce a model of ‘best practice’ within innovation:

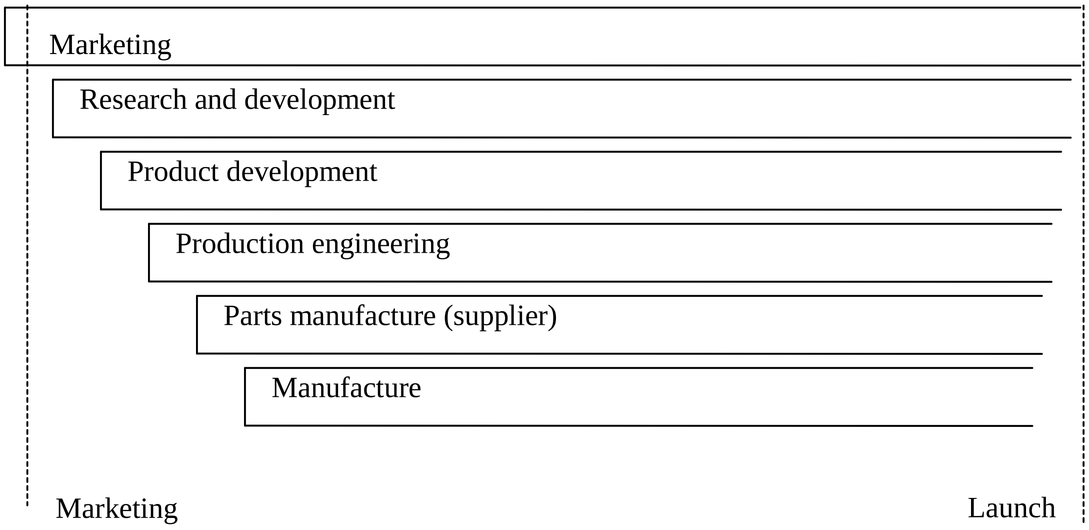

Figure 12: The Fourth Generation Process Model (The Integrated Model) [Source: Rothwell, (1994, p.12)]

This model not only ensured that there was a greater degree of communication between the different actors within the process; but that products would reach the market more quickly than if they had used the previous sequential models. A variant on this model is described by Kline and Rosenberg (1986), a simplified version of which is provided in Figure 13 below:

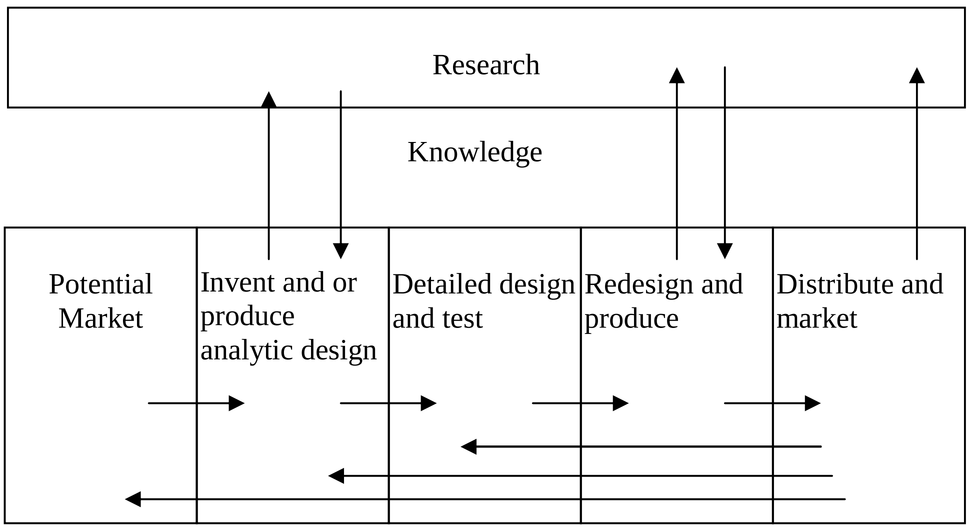

Figure 13: The Fourth Generation Process Model (The Chain Linked Model) [Source: Derived from Kline and Rosenberg (1986, p.290)]

Campodall'Orto and Ghiglione (1996) state that this particular version of the integrated model is based on two main principles: overcoming the previous linear models; and encouraging links between science and technology. They argue that it is necessary to overcome the previous linear models as they do take account of the feedback loops which are a vital part of the innovation process. These feedback loops show the interaction between both ‘blue sky’ research (science) and applied research (technology).

Rothwell’s Fifth Innovation Process Model, entitled the Systems Integration and Networking (SIN) model, is a continuation of the integrated model with its emphasis on networking, parallel development, and corporate flexibility. A model for the 1990s, it reflects the economic situation with intense competition, increasing use of information technology, and increased partnerships between organisations. Unlike previous models, Rothwell places a much higher emphasis on the tools that underlie the process or the knowledge transfer support systems. Rothwell (1994) characterises this model in two ways: its underlying strategy elements and its primary enabling features, as presented in the table below:

Underlying Strategy Elements:
Time-based strategy (faster, more efficient product development)
Development focus on quality and other non-price factors
Emphasis on corporate flexibility and responsiveness
Customer focus at the forefront of strategy
Strategic integration with primary suppliers
Strategies for horizontal technological collaboration
Electronic data processing strategies
Primary enabling features:
Greater overall organization and systems integration
Flatter, more flexible organizational structures for rapid and effective decision making
Fully developed internal databases
Effective external data link

Table 8: Characteristics of the Fifth Generation Process Model [Source: Derived from Rothwell (1994, pp.7-31)]

Rothwell thus emphasises the importance of two elements within the innovation process: firstly, the importance of the relationships which exist between the different groups of actors; and secondly the use of information and knowledge and stored within systems. In the same vein, DeBresson and Amesse (1991, p.364) continue and extend this notion of the importance of relationships by positing the notion of ‘knowledge clusters’, or ‘networks of innovators’. They go so far as to suggest other similar terms used synonymously such as ‘seamless web’, ‘innovation clusters’, ‘complex web of interactions’ and ‘development pole’. They argue however that each term has a different focus of analysis: ‘All these terms refer descriptively to the same observed features, each with a slightly different analytical emphasis. Innovation clusters focus on the close proximity of innovations in economic space, sometimes resulting in spontaneous agglomeration. Technopoles and systems refer to the structure of linkages that shape the economic landscape, whereas network analysis focuses on the configuration, the nature and content of a set of inter-organizational relationships.’

DeBresson and Amesse (1991, p.364) state that innovative networks have specific advantages over internalised development: ‘If innovation consists of new technical combinations, networks provide the flexibility with which to exploit opportunities for the recombination of various components.’ Consequently, this flexibility given by a network allows the organisations to reconstitute their individual input in a number of different ways. In fact, it may well be the network itself, through cross-fertilisation of ideas, which provides the ideas of potential applications of each body of knowledge. Thus, DeBresson and Amesse also tacitly support the broader socio-economic context of the knowledge economy as being characterised by the use of organisational and personal networks as tools for the exchange of information and knowledge (Tapscott, 1996; Kelly, 1998).

Teubal et al (1991) argue that networks are an essential feature to ensure successful innovation. Although DeBresson and Amesse (1991, p.366) state that: ‘All technological transactions (i.e., innovation ventures, technological transfers, adaptions, and straight adoption) seem to be organizationally embedded, because internalization better guarantees appropriation.’ They point out that the very existence of networks for knowledge transfer supports the idea that some types of organisational linkages can be used (and are arguably essential for) the successful transfer of certain types of knowledge, particularly concerning innovation.

As stated above, Rothwell argues that government policy has changes to encourage organisational linkages for knowledge transfer, particularly between higher education and industry. However, stimulating an environment cannot be seen to be sufficient reason in itself to join networks. DeBresson and Amesse (1991, p.368) state that: ‘networks may be a useful way to evaluate each other’s technologies while ensuring reciprocal non-cash payments of technical know-how.’ Shared risks and cost are also a powerful incentive; however these short-term benefits are again not enough to justify linkage, ‘unless significant long-term benefits were expected to outweigh the immediate cooperation costs.’

DeBresson and Amesse (1991) suggest then that an inter-organisational network will yield potentially more financially rewarding products, than those innovations developed internally, and in relation to this research, this may be seen to be attributable (at least in part) to the acquisition and transfer of knowledge. Arguably, an organisation within a network has access to the sum of the knowledge within that network which will obviously be greater than the knowledge within the organisation itself. However it is debatable whether there can be seen to be a direct correlation between the ‘amount’ of knowledge held within a network and the potential of that network to generate innovation.

All of the models, from first to fifth generation, are a vital part of understanding the innovation process. However, what they do not explain (with the exception of the fifth generation process) is how these processes can be implemented. This limitation can be seen in a number of different issues concerning innovation. Faulkner emphasises the lack of specific coverage by these models to address the large number of different types of networks: ‘Yet in spite of this intense interest, and a growing body of policy research on the subject, the debate surrounding public-private sector research linkage tends to be analytically shallow in a number of important aspects. In particular, it fails to address the diversity in the nature and extent of such linkage’ (Faulkner, 1992, p.2).

These factors are of course not unrecognised, as Rothwell suggests: ‘The reality is more complex, in that even today all types of innovation process continue to exist in various forms. To some extent this diversity is a result of sectoral differences, i.e. innovation in certain consumer products has a strong market-pull flavour, innovation in assembly industries is becoming more integrated and parallel in nature, while innovation in science-based industries such as pharmaceuticals leans more towards the 'science discovers, technology-pushes' mode' (Rothwell, 1994, p.23).

Importantly, Nobelius notes that while the five models of R&D generations are often presented on a timescale they ‘hold components or ideas still valid and sought for by many companies, and hence do not represent a map of where companies today are to be placed’ (Nobelius, 2004, p.369). Although a sixth generation of innovation or R&D management has been suggested by a number of writers, the actual form and content of this model has not been elaborated on in any great detail. Nobelius however predicts a specific direction: ‘This shift towards sixth generation of R&D management is predicted to return to the roots, i.e. back to the purpose of the first generations corporate research labs, one pursuing more radical innovations’ (2004, p. 374).

Based on a number of case studies, Nobelius (2004, p.369) suggests that a new set of approaches to R&D management will be based on 'a broader multi-technology base for high-tech products and a more distributed technology-sourcing structure.' Nobelius (2004) goes on to propose a panoply of strategic approaches, although he is careful to note that the specific choice of approach or approaches are highly dependent on the context within which they are placed. How much this proposed model differs from the fifth generation model is open to debate, and its potential impact on organisations is, at present, unquantifiable.

The importance of the generations of R&D management is that they suggest an evolution of thought which has developed since the 1950s. As Nobelius (2004, p. 375) suggests: 'It is important to realize that the notion of R&D generations is one way of communicating different management approaches under certain conditions and contexts.' However, Ortt and van der Duin (2008, p.522) propose that while these models may have provided an accurate historical framework with which to examine innovation at specific points in time 'current innovation practices suggest that innovative companies do not automatically follow the best practices as prescribed by the dominant model of their time.' Echoing Rothwell's perspectives on the differences between the theory and the practice of innovation, Ortt and van der Duin (2008) suggest that a much more contextual approach to innovation management from both theorists and practitioners alike is much more appropriate in the current socio-economic climate. Their suggestion emphasises the need for both highly contextually based research in innovation management, and also reiterates the postmodern sentiment of the demise of grand narratives.

2.7 Summary

This chapter has aimed to provide a review of the literature pertinent to this research. The socio-economic perspective is presented within the first section of this chapter which discusses the development and defining characteristics of the knowledge economy. As well as the obvious impact of information and communication technologies, the importance of the innovation process within this context is evident. These socio-economic characteristics can also be seen to have acted (at least to a degree) to catalyse the formation of the field of knowledge management, which both formally recognises the importance and value of knowledge within organisational contexts: 'The current focus on KM thus appears to reflect fundamental and convergent shifts in thinking about organization as well as substantive changes in the competitive context of organizations. These shifts recognize the decline of traditional manual work and the importance of innovation, knowledge work and knowledge workers in an era described variously as the ‘information age’, the ‘knowledge society’ and the ‘post-industrial era’ (Swan and Scarbrough, 2001, p.1).

Clearly, one of the most significant issues in work of this type is the difficulty in applying a working definition of knowledge which is applicable within this context. This problem is further compounded not only by the different perspectives through which knowledge may be viewed which have been highlighted here as a philosophical perspective (and specifically the postmodern perspective) and a socio-economic perspective, but also the critical debate concerning tacit and explicit knowledge. Spender (2005, p.135) neatly encapsulates this point: ‘The most obvious squabble of this type is between those who see tacit knowledge as quite distinct from explicit knowledge, and those who ‘smoosh’ them together saying all ‘knowledge’ is on a spectrum that has ‘completely explicit’ at one end and ‘completely tacit’ at the other end.’ Within the context of this research, the second approach is evident and is discussed further in the remaining chapters.

Both philosophical and socio-economic perspectives of knowledge have been presented, and it is evident that both perspectives are necessary if a definition of knowledge is to be identified and applied. This chapter has identified a ranged of different knowledge-based processes which collectively form a systemic approach to the management of knowledge as an organisational resource. These have also been examined in relation to the innovation process which has revealed the differences in the extent to which these manifest themselves within this process. However, as the literature shows, although understanding of different innovation models has developed chronologically, there is still no certainty that any novel concept will result in the development of an innovative technology.

The last section within this chapter has examined both the innovation process from a developmental perspective, as well as acknowledging the importance of knowledge within the process itself. More recent models of innovation can be seen to make this link increasingly specific, and this helps to substantiate the need for this research. These models also imply the broader context of the knowledge economy as they acknowledge the importance of networking between the various actors, the use of information and communication technologies, and obviously the role of knowledge itself.

The literature shows that there is an understanding that knowledge plays a critical role within the innovation process. While previous research exists which explores the relationships between knowledge and innovation this has focussed on specific knowledge-based activities within the innovation process, or the forms and types of knowledge present within it. No prior research exists which draws together all six knowledge-based processes (identified by Burnett et al, 2004), and the forms and types of knowledge present within these processes. Additionally, no previous research has examined the role of knowledge within the innovation process of the UK upstream oil and gas industry itself.

CHAPTER THREE: METHODOLOGY

‘Ask a question and you're a fool for three minutes; do not ask a question and you're a fool for the rest of your life.’ (Chinese Proverb)

3.1 Introduction

In order to achieve the aim and objectives identified in Chapter 1, and underpinned by the review of the literature and the contextual framework presented in Chapter 2 and Appendix IV respectively, a research approach was developed employing techniques in use within the field of social science. The purpose of this chapter is to justify the research methods selected and employed within this research; to explain how these methods have been applied within this study; and to provide an overview of the stages within the research process.

The chapter provides an outline of the main research paradigms adopted and goes on to demonstrate the particular methodological approach taken within this research. The process of defining the research area is outlined with a justification as to why this research area was selected. An overview of the sources, structure and content of the literature search is also provided. The process of sample selection is covered, along with the issues encountered in producing a sample frame for this research. The chapter goes on to examine the narrative interview method used within the research, and specifically examines this method in relation to the research. Critically, it also describes the process of developing a hybrid methodological ‘tool’ combining elements of narrative schema with Soft Systems Methodology (SSM), as well as its subsequent application to the deconstruction and reconstruction of primary data. Drawing on the literature as presented in Chapter 2, the chapter also presents the analytical template developed to identify the forms, types and knowledge processes present within the technological innovation process.

As can be seen from the third research question, a critical element of this research is the development and application of a novel methodological approach. This has been included within the objectives of the research for a number of reasons. The development of new research tools within the field of social science is essential if the tools themselves are to be effective within constantly changing societal contexts. The tools themselves must seek to acknowledge societal changes and encompass these within their scope and function, as the tools themselves allow for societal analysis. Equally, the methods used within social science research have different strengths and weaknesses which lend themselves to different types of research. As Bauer, Gaskell and Allum (2000, p.7) suggest: 'By analogy, neither the survey questionnaire nor the focus group is the royal road for social research. This route can, however, be found through an adequate awareness of different methods, an appreciation of their strengths and weaknesses, and an understanding of their use for different social situations, types of data and research problems.'

3.2 Research: Types, Paradigms and Levels

Before examining the practicalities of the research process, it is important to understand the nature of the research itself. Denzin and Lincoln (1998, p.2) provide the following definition of qualitative research: 'Qualitative research is multimethod in focus, involving an interpretive, naturalistic approach to its subject matter. This means that qualitative researchers study things in their natural settings, attempting to make sense of or interpret phenomena in terms of the meanings people bring to them. Qualitative research involves the studied use and collection of a variety of empirical materials-case study, personal experience, introspective, life story, interview, observational, historical, interactional, and visual texts – that describe routine and problematic moments in individuals' lives.' Although somewhat lengthy, the definition is useful in that it highlights a number of pertinent factors: the approach to the subject matter; the environment within which the research is conducted; the sources of data and information used; and importantly the interpretation of phenomena.

As shall be seen from the content of this chapter, the research approach taken was highly qualitative in nature due to the types of data required to address the objectives set for the research, and the highly qualitative nature of the topic itself discussed in the previous chapter. Although it may be obvious, it is important at this stage to acknowledge the approach taken, and why this approach was appropriate to the field of study. In the words of Filstead: 'Quantitative and qualitative methods are more than just differences between research strategies and data collection procedures. These approaches represent fundamentally different epistemological frameworks for conceptualizing the nature of knowing, social reality, and procedures for comprehending these phenomena' (Filstead, 1979, p.45).

Within any qualitative research project, one or more of a number of approaches or paradigms may be applied in order to provide a structure for the research. Hussey and Hussey (1997, p. 47) state that paradigms 'offer a framework comprising an accepted set of theories, methods and ways of defining data.' Paradigms therefore help to ensure validity by applying existing appropriate methodologies to the research. There are two main research paradigms or approaches to the social science research process: the positivistic paradigm and the phenomenological paradigm. These however should not be seen as distinct and isolated approaches, but rather as different ends of a research spectrum. The difference between these two paradigms can be perceived as the way in which they view 'reality'.

Morgan and Smircich (1980, p.492) state that these paradigms may be viewed as a 'continuum' with six key stages (see Table 9) ranging from extreme positivist in which the researcher makes the assumption that 'reality is an external, concrete structure which affects everyone', to an extreme phenomenologist paradigm where 'there may be no social world apart from that which is inside the individual's mind' (Hussey and Hussey, 1997, p.51). This can be seen to be closely related to the philosophical assumptions that guide research adapted from Guba and Lincoln (1988) by Creswell (1997), and more specifically the ontological assumption which challenges the nature of reality as viewed by the participants within the study. As Creswell states: 'Briefly, the ontological issue addresses the nature of reality for the qualitative researcher; reality is constructed by individuals involved in the research situation. Thus, multiple realities exist, such as the realities of the researcher, those of individuals being investigated, and those of the reader or audience interpreting a study' (Creswell, 1997, p. 76).

Positivistic		Approach to social sciences		**Phenomenological**	
←———	———	———	———	———	———→
Reality as a concrete structure	Reality as a concrete process	Reality as a contextual field of information	Reality as a realm of symbolic discourse	Reality as a social construction	Reality as a projection of human imagination

Table 9: Research Paradigms [Source: Morgan and Smircich (1980, p.492)]

Hussey and Hussey (1997, p.54) identify several specific features of the main paradigms (see Table 10 below). These features can be seen to relate to the types and forms of the data gathered, and consequently influence the methodologies (or data-gathering tools) selected which are appropriate to the specific data types.

Positivistic Paradigm	Phenomenological Paradigm
Tends to produce quantitative data	Tends to produce qualitative data
Uses large samples	Uses small samples
Concerned with hypothesis testing	Concerned with generating theories
Data is highly specific and precise	Data is rich and subjective
The location is artificial	The location is natural
Reliability is high	Reliability is low
Validity is low	Validity is high
Generalises from sample to population	Generalises from one setting to another

Table 10: Research Paradigms and data [Source: Hussey and Hussey (1997, p.54)]

Morgan and Smircich (1980, p.492) suggest that paradigms operate on three specific levels: a philosophical level; a social level; and a technical level. Within the context of this research, the philosophical level paradigm ('where it is used to reflect basic beliefs about the world') can be seen to be highly phenomenological and is based on a postmodernist/post-structuralist perspective (Barthes, 1981; Kristeva, 1986; Jameson, 1991; Lyotard, 1984). The importance of adopting a philosophical stance (and specifically when conducting research in which information or knowledge management play a role) is made clear by Wilson (2002) who suggests that '...method without a philosophical framework that determines why a particular method is employed and what view of reality the research holds, is purely mechanistic.'

Across the stages of the research process, a phenomenological paradigm has been applied at a social level 'where it is used to provide guidelines about how the researcher should conduct his or her endeavours' (Hussey and Hussey, 1997, p.47). Methodologies appropriate to this paradigm (semi-structured narrative interviews) have been employed as they were considered to be those most appropriate to ensuring the capture of data necessary to achieve the aims and objectives of the research. The application of these methodologies will be discussed in greater detail throughout in this chapter. Lastly, paradigms are applied at a technical level in order 'to specify the methods and techniques which ideally should be adopted when conducting research' (Hussey and Hussey, 1997, p.47).

Although the research paradigms are addressed at the social and technical level in relation to each stage of the research process later in this chapter, it is worth reflecting on how postmodernism/post-structuralism have a bearing on the methodological approach taken at a philosophical level. In relation to the concept of knowledge itself, these philosophical perspectives can be seen to focus on two main areas relevant to this research. The postmodern perspective challenges the content of what is perceived to be ‘knowledge’ in a societal sense (Lyotard, 1984), whereas the poststructuralist perspective challenges the structure of that knowledge within a codified textual environment (Landow, 1992).

Specifically, Klages (2003) suggests that postmodernism is also concerned with the relationship between knowledge processes and the use of ICTs: ‘Not only is knowledge in postmodern societies characterized by its utility, but knowledge is also distributed, stored, and arranged differently in postmodern societies than in modern ones...In postmodern societies, anything which is not able to be translated into a form recognizable and storable by a computer - i.e. anything that's not digitizable - will cease to be knowledge. In this paradigm, the opposite of "knowledge" is not "ignorance," as it is the modern/humanist paradigm, but rather "noise." Anything that doesn't qualify as a kind of knowledge is "noise," is something that is not recognizable as anything within this system’ (Klages, 2003).

Similarly, Lyotard challenges the legitimacy of knowledge and the processes by which knowledge is legitimised. Lyotard (1984) suggests that within the knowledge-based society which utilises information and communication technologies to support our interactions with data, information and indeed knowledge, knowledge is legitimised in ways different to previous societal models. This does not in itself argue against the forms of knowledge as presented by Polanyi (1966), however it does suggest that knowledge which is not in this form is somehow less ‘legitimate’. The relationship between (the forms of) knowledge and technology is important in terms of the research, specifically in relation to the fourth objective set for the research.

Secondly (and with specific reference to the work of Lyotard) it rejects the exclusivity of the value of scientific knowledge over narrative knowledge (Lyotard, 1984). Dow (2006) suggests that ‘Narrative knowledge is obtained from a narration of an experience. It makes use of common linguistic symbols. Scientific knowledge is obtained from a scientific publication that uses diagrams, esoteric mathematical and technical symbols, *etc*.’ In fact, Lyotard (1984) argues the ‘inferiority’ of scientific knowledge in relation to narrative knowledge due to the need to share scientific knowledge through narratives. Additionally, Lyotard rejects the concept of what are termed ‘grand narratives’ (which include the identification of scientific knowledge as the dominant form of knowledge).

Postmodernism and post-structuralism represent a paradigmatic shift in the way in which (Western) society may view itself. As societies adopt different philosophical perspectives, so too must they develop tools with which to examine themselves. This move is perhaps the fundamental reason why story and narrative were shunned as legitimate tools for research, and now are increasingly adopted by researchers within a wide variety of branches of the social sciences, including anthropologists, historians, linguists, psychologists and sociologists (Boje, 2001, p.7; Jovchelovitch & Bauer, 2000, p.57; Lieblich et al, 1998, p.1).

In relation to social science research, the move from a modernist/structuralist to postmodernist/post-structuralist perspective represents a move from a highly positivistic approach where meaning was viewed as derived from hard scientific facts, to a more phenomenological, if not post-phenomenological (Ihde, 1998; Verbeek, 2005; 2006) approach, where qualitative factors are as important (if not more important) that quantitative factors. Specifically in relation to this research, this move is reflected by the acknowledgement of the importance of narratives from both a philosophical and methodological perspective. As Lieblich et al state: 'The use of narratives in research can be viewed as an addition to the existing inventory of the experiment, the survey, observation, and other traditional methods, or as a preferred alternative to these "sterile" research tools' (Lieblich et al, 1998, p.1).

This move however has not been unproblematic. The use of story and narrative within the field of social science has struggled to be taken seriously as legitimate methods for social science research as Czarniawska contends: 'The traditional view is that science should keep to facts and logic, leaving metaphors and stories to literature, this being a sediment of premodern times and oral societies' (Czarniawska, 1998, p.7). What Czarniawska seems to be describing is the difficulty in not necessarily abandoning methodological approaches more accepted within a modernist tradition (and thus somehow more valid), but in broadening the methodological spectrum to include methodologies which are closer to a postmodern approach including storytelling. Cynically perhaps, narratives and narrative analysis can also be seen to be formalized attempts to legitimize the use of story, especially within the context of academic research, as Gabriel asserts: 'The relationship between academic research and storytelling has been ambiguous. In many ways, science has stood as the opposite of storytelling, seeking to replace the lore of 'old wives tales' with provable generalizations' (Gabriel, 2000, p.3).

This difficulty is also outlined by Usher (2001, p.47): 'We are so used to thinking of research as providing a special kind of methodologically validated knowledge about society that it's not easy to accept the notion of research as story-telling. We think of story-telling as 'unserious', as fictional, whereas the dominant image of research is that it is about finding the 'truth' and therefore an altogether more serious business. Equally, it's not easy to accept that any account of research is itself an example of telling a story since explicating the ‘nature’ of research through the notion of a story does not somehow seem appropriate’ (Usher, 2001).

The first of these assertions is echoed by separately by both Boje (2001) and Riessman, albeit in rather differing ways. Boje asserts that traditionally ‘story has been viewed as less than narrative. Narrative requires plot, as well as coherence. To narrative theory, story is folksy, without emplotment, a simple telling of chronology’ (Boje, 2001 p.1). Boje therefore implies a two tiered value system where narrative can be viewed as a more rationalist and structured (and presumably more) valid approach than simple storytelling, which consequently helps to justify narrative analysis as a legitimate tool within social science, but very much leaving storytelling out with this legitimisation. ‘Narrative analysts replace folk stories with less messy academic narrative emplotments and create an account of organizations that is fictively rational, free of tangled contingency and against story’ (Boje, 2001 p.1).

Riessman is rather less judgmental about the role and value of story in relation to narrative: ‘Story telling, to put the argument simply, is what we do with our research materials and what informants do with us’ (Riessman, 1993, p.1). Riessman therefore puts story itself at the heart of narrative analysis rather than something beneath it: ‘Narrative analysis takes as its object of investigation the story itself’ (1993, p.1). In other words, there can be no narrative analysis without story.

Usher (2001) seems to suggest that story-telling does not lend itself to finding truths, however as Riessman points out: ‘Interpretation is inevitable because narratives are representations. There is no hard distinction in postpositivist research between fact and interpretation’ (Reissman, 1993, p.2). In effect then, the objection to the use of story and narrative from a traditional social science perspective is the lack of ‘truths’ due to their interpretive or subjective natures.

Naturally it is the subjective nature of both stories and narratives that is the differentiating factor between these and other textual analysis approaches in the social sciences. As Riessman points out: ‘Subjectivity, of course is deeply distrusted in mainstream social science, which values context-free laws and generalized explanations...yet in personal narratives, “it is precisely because of their subjectivity – their rootedness in time, place, and personal experience, in their perspective-ridden character – that we value them”’(1993, p.5).

This concept of the legitimacy of story, not just as a tool for social science, but as a representation or interpretation of facts and truths is also addressed by Lyotard in relation to the field of science, one which would seem to whole-heartedly reject storytelling due to its complete opposition to positivism: '…as Lyotard (1984) made abundantly clear, scientists tell stories about their data and use stories to sell their story' (Boje, 2001, p.7).

Yet despite these objections to both story and narrative as legitimate methods for research, both have been used widely within a variety of branches of social science. Indeed Todorov coined the term 'narratology' in an attempt to lift the study of narrative 'to the status of an object of knowledge for a new science' (quoted in Godzich, 1989, p. ix). Clearly then there is now a need to examine the role of story-telling and perhaps more importantly narrative analysis to ensure that they are regarded as valid methodologies. Despite the rise in interest in the use of narratives within the social sciences, Lieblich et al suggest that 'the use and application of this research method seems to have preceded the formalization of a philosophy and methodology parallel to the practice' (Lieblich et al, 1998, p.1). Thus, this research presents one attempt to apply philosophical perspectives to the use of narratives, and also to develop a methodological approach which considers the role of narratives within it.

The other vital consideration in relation to this research is the way in which knowledge is viewed within postmodern societies. As Klages somewhat wryly suggests: '…postmodernism is concerned with questions of the organization of knowledge. In modern societies, knowledge was equated with science, and was contrasted to narrative; science was good knowledge, and narrative was bad, primitive irrational (and thus associated with women, children, primitives, and insane people)' (Klages, 2003).

Lyotard (1984) suggests that technology has driven the way in which we communicate and as such has an impact on knowledge itself: 'Its two principal functions – research and the transmission of acquired learning – are already feeling the effect, or will in the future.' (Lyotard, 1984, p.4). These sentiments are echoed by Sarup who takes a more direct approach in his examination of post-structuralism and postmodernism. Sarup, in his examination of Lyotard's work states that: 'He [Lyotard] predicts that anything in the constituted body of knowledge that is not translatable into quantities of information will be abandoned and the direction of new research will be dictated by the possibility of its eventual results being translatable into computer language' (Sarup, 1993, p.133).

Both postmodernism and post-structuralism can be seen to play significant roles within this research by providing a philosophical framework. This does not only impact on the way in which both scientific and narrative knowledge are perceived within the context of this research (Lyotard, 1984, Kristeva, 1986; Barthes, 1981; Landow, 1997), but also on specific stages within the research process as will be further discussed below.

3.3 Stages within the Research Process

The aim, objectives and research questions for the research have already been identified within the introductory chapter of the thesis. However the methodological approaches used within the research in order to achieve these set objectives and answer the research questions can be identified and related as follows:

Aim: To develop further understanding of the role of knowledge within the technological innovation process within the UK upstream oil and gas industry		
Research Question 1: What prior research exists in the areas relevant to this research?	**Objective 1:** To conduct a literature search and subsequent review and analysis of material in disciplines relevant to this research.	**Methodological Approach:** Literature review
Research Question 2: Who are the actors within the technological innovation process in the UK upstream oil and gas industry, and what are their roles?	**Objective 2:** To develop generalisable typologies and characterisations of the actors involved in the process of technological innovation within the UK upstream oil and gas industry, and the relationships existing between them.	**Methodological Approach:** Gather and analyse relevant data using the analytical template developed in order to fulfil objective 3 of the research
Research Question 3: Can a methodology be developed to examine the knowledge-based processes, and forms and types of knowledge within the innovation process?	**Objective 3:** To develop a methodological approach by which data relating to knowledge-based processes, and forms and types of knowledge within the innovation process may be examined.	**Methodological Approach:** Synthesise existing analytical approaches in order to develop an analytical template which may subsequently be applied to achieve objectives 2,5 and 6 of the research
Research Question 4: How can the actors' explicit knowledge of the innovation process be codified and transferred?	**Objective 4:** To develop a tool which may be used to store, structure and transfer the explicit knowledge of actors relating to the process of technological innovation.	**Methodological Approach:** Structure the data using elements of the template developed to fulfil objective 3 and store the data gathered to fulfil objectives 2,5 and 6 within a hypertextual narrative system
Research Question 5: What forms and types of knowledge are utilised within the innovation process?	**Objective 5:** To develop generalisable typologies and characterisations of the information and knowledge that is the content of various knowledge-based processes between actors.	**Methodological Approach: :** Gather and analyse relevant data using the analytical template developed in order to fulfil objective 3 of the research
Research Question 6: What knowledge-based processes occur within the innovation process?	**Objective 6:** To identify the knowledge-based processes which exist within the process of technological innovation.	**Methodological Approach:** Gather and analyse relevant data using the analytical template developed in order to fulfil objective 3 of the research

Table 11: Aims, Objectives, Research Questions and Methodological Approach

The aims and objectives for the research were achieved through a four stage process. However as can be seen from the methodological approach taken in relation to each research question and objective, the research questions and objectives were not achieved in a sequential manner. The stages within the process were: a literature search; a preliminary study; and a two-part main study (which included a pilot of the methods used). These stages will be described in detail, however prior to this it is important to understand how these fit in to the overall process (or as it is often referred to, the cycle) of enquiry which can be seen to encompass all elements of the research process, and describes the 'dialectic relationship between theory, practice, research questions, and personal experience' (Marshall and Rossman, 1999, p.25).

Although a number of different research cycles have been proposed such as Crabtree and Miller's cycle entitled 'Shiva's circle of constructivist enquiry' (Crabtree and Miller, 1992, p.10), they can all be seen to be broadly similar in relation to the elements they include. Perhaps the most basic is that presented by Bruce:

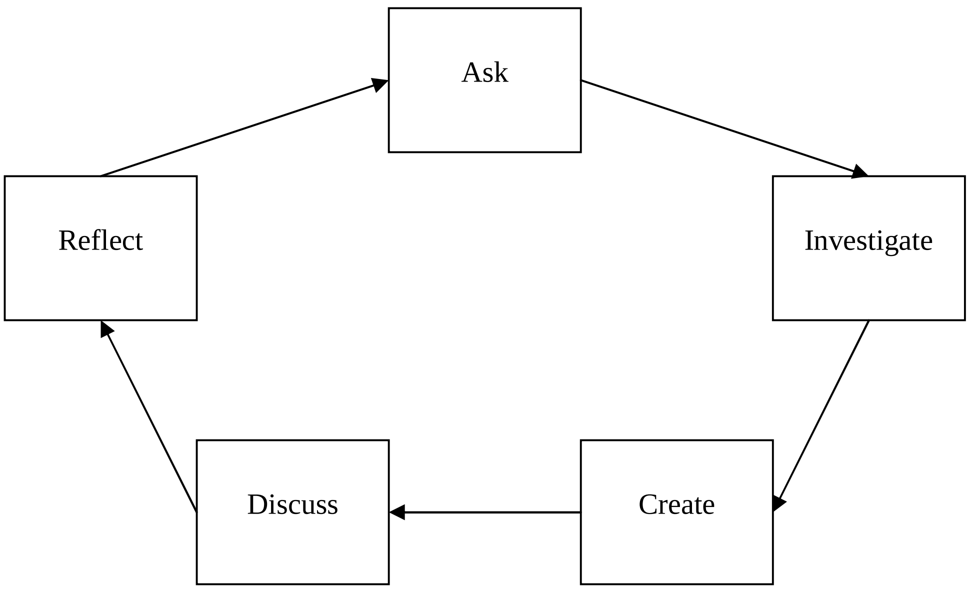

Figure 14: The Cycle of Inquiry [Source: Derived from Bruce and Davidson (1996, pp.281-300)]

Drawing on the work of Dewey (1938; 1956), Bruce & Davidson (1996) suggests that the cycle of inquiry describes the four key interests of any learner: the desire to learn, communicate, create, and extract meaning. '[The cycle of inquiry] places these primary interests of the learner in the framework of a cycle of inquiry. For any question or problem, one may then think of activities of Investigation, Creation, Discussion, and Reflection as means for its resolution' (Bruce and Davidson, 1996, p.290). These can be seen to be equally applicable to the researcher as to the learner, as discussed below.

Although these activities may appear to be rather theoretical, they can be seen to practically manifest themselves within the structure of the thesis: the area for investigation is identified within the introductory chapter, and the research questions posed (Ask); the contextual framework identifies and examines the sector within which the research is carried out (Investigate); the literature review continues the investigation itself through an examination of previous work in the areas pertinent to the research (Investigate) ; the methodology chapter describes the development and application of the research tools which are used to collate and analyse the primary data (Create); the discussion and analysis chapters describe what was discovered during the research process (Discuss); and the concluding chapter provides a reflective element to the work (Reflect).

The following diagram presents each of the elements within the research process and shows the logical order in which they were carried out:

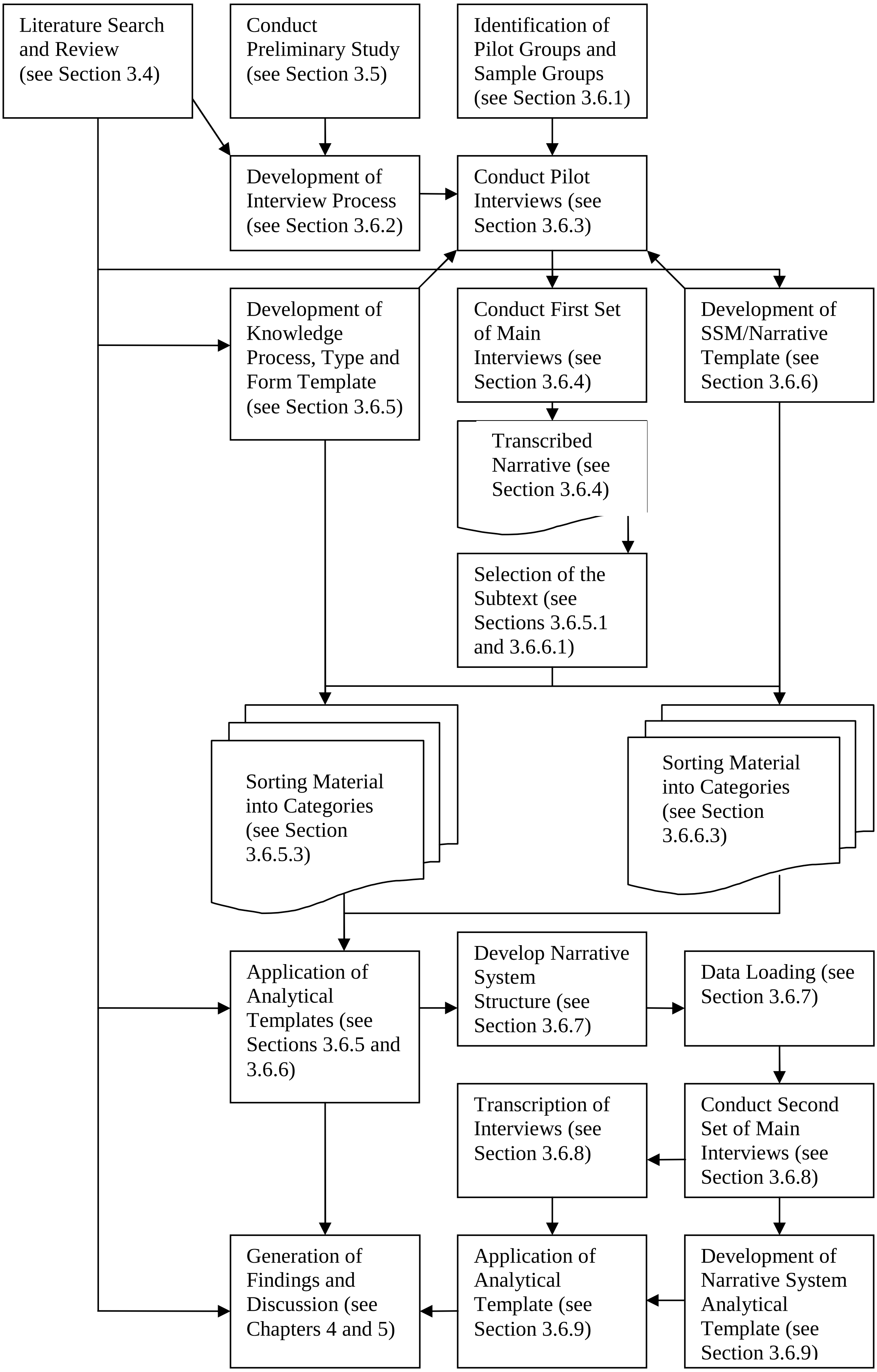

Figure 15: The Research Process

3.4 Literature Search and Review

Prior to the primary research being conducted, a literature search and review was conducted. The literature search was initially conducted full-time for the first four months of the project, and was continued on a regular basis throughout the course of the research project. There were several reasons why a literature review was conducted for this research. Firstly, given the range of topics covered, it was critical to identify prior research which would provide an opportunity to consider and subsequently select or reject theoretical models and theories which would inform the research as well as the practical considerations given to conducting social science research. The review also provided relevant material for the industrial and socio-economic backdrops to the research presented by the contextual framework (see Appendix IV) and the knowledge economy (see Section 2.2). Additionally, given the multidisciplinary nature of the work, it was essential to identify areas in which the relevant disciplines converge in relation to both theory and practice.

3.4.1 Topics

The literature search initially sought to identify existing work in the areas of knowledge management and innovation. This work included case studies of organisational approaches to knowledge management and innovation in order to identify how organisations were practically seeking to engage with these topics, as well as the key theories within the areas of innovation and knowledge management. The purpose of this was to help to identify a hypothesis for the research, the research questions, and also to begin the process of identifying a suitable methodological approach.

However, the topics covered by the literature search broadened as the review of the literature progressed, and the research questions themselves became more concrete. These can be categorised into the following broad but (as discussed in the previous chapter) related topics:

- Innovation/commercialisation/technology transfer processes
- Knowledge, knowledge management and the knowledge economy
- Information and communication technologies
- Postmodernism and post-structuralism
- Social science research methodologies
- The upstream oil and gas industry

There has been a wealth of literature published over the last thirty years relating to the innovation, commercialisation and technology transfer processes, with a range of theoretical models of these processes being proposed. The innovation/commercialisation processes section within the literature review identified appropriate theories of innovation/commercialisation with particular reference to the commercialisation of new technologies and the interaction of the various players (identified within this research as providers, enablers and end-users) within the theoretical models. As part of this topic, the issue of technology transfer was also examined. Specifically, this sought to examine the transfer of technological knowledge between organisations, or within different departments within organisations.

The literature search relating to knowledge and knowledge management sought to identify material pertaining to a broad range of subjects. Initially, material was identified around the philosophical and socio-economic perspectives on knowledge. As such this work was grounded in the works of the classical Greek philosophers such as Socrates and Aristotle, but also included much more recent works from writers such as Polanyi (1966). From a socio-economic perspective the search focussed on the perceived change of importance and role of knowledge within the current context of the knowledge economy. At a more operational level material was sought relating to the specific knowledge-based processes (such as the transfer of knowledge) identified by theorists, and how these processes manifest themselves in practice-based contexts within organisations.

The literature surrounding information and communication technologies related to the use of ICTs (and more specifically internet-based technologies) to support knowledge-based processes. As part of this the literature search also sought to identify material relating to the application of internet-based technologies as supporting mechanisms for stories and narratives (as these emerged as potential candidate methods for this research), with particular reference to how the functionality of internet-based technologies could potentially support narratives with a postmodern context.

The section of the literature concerned with postmodernism and post-structuralism sought to establish an understanding of the current philosophical context which heavily impacts both on present understanding of the nature of knowledge, the role of information and communication technologies, and lastly the importance of storytelling both as a valid methodology within the social sciences, and as a method of knowledge sharing.

The literature search relating to the research methodology literature sought to identify appropriate methodologies for the acquisition, structuring and analysis of data currently in use within the social sciences which may have been applicable within this research. Although initially the search included both qualitative and quantitative methodologies, this was narrowed down to qualitative methodologies given the nature of the research area. Primarily this focussed on the use of stories and narratives within the social sciences both as means of data elicitation (in the form of narrative interviewing) and as forms of data representation. Additionally, narrative analysis and Soft Systems Methodology (SSM) were examined in relation to the data analysis stage of the research, and these are discussed in more detail later in this chapter.

Although these areas may appear to be clearly definable, there were a number of overlaps between several sections which can be seen to be reflected in the structure of the literature review chapter. In addition to these areas, supplementary literature was gathered in order to develop and understanding of the context within which this research is placed. This provided the material for the second chapter which provided a contextual framework for the research. This material primarily related to the development of the oil and gas industry from a global perspective, the regional perspective of the development of the industry in the UKCS and its subsequent economic importance to the UK, the importance of technological innovation within this context, and the key players in the technological innovation process within the UK upstream oil and gas industry.

3.4.2 Sources

In relation to the topics identified above, the following table outlines some of the main keywords which were identified and used within the literature search and review:

Topic	**Keywords**
Innovation/commercialisation/technology transfer processes	Innovation, commercialisation, technology transfer
Knowledge, knowledge management and the knowledge economy	Knowledge, knowledge management, organisational learning, knowledge acquisition, knowledge sharing, knowledge transfer, knowledge dissemination, knowledge use, knowledge application, knowledge creation, knowledge measurement, valuation, knowledge economy, digital economy, post-industrial society, information revolution, information society, economics, capitalism, late-capitalism
Information and communication technologies	Knowledge-based systems, knowledge discovery, digital narrative, hypertextual narrative, cybertext, interactive narrative, interactive storytelling, digital storytelling
Postmodernism and post-structuralism	Postmodernism, postmodernity, modernism, modernity, post-structuralism, structuralism
Social science research methodologies	Social science, research enquiry, qualitative methodology, quantitative methodology, soft systems methodology, narrative analysis, narratology, analysis of qualitative data.
The upstream oil and gas industry	Oil industry, North Sea oil, oil and gas industry initiatives, upstream industry, technological innovation.

Table 12: Literature Topics and Keywords

Much of the literature located was comprised of journal articles and monographs; however a number of key conference papers, grey literature and online sources were also identified and used. These sources were particularly important in relation to work conducted by public sector bodies (such as OECD, The Scottish Government and BIS) in the area of the knowledge economy, and also in relation to industry initiatives (such as Pilot and CRINE) in the UK oil and gas industry.

A number of databases were used as key sources for relevant journals, journal articles and bibliographies, and these included:

- Business Source Premier
- Emerald
- International Bibliography of the Social Sciences
- Informaworld
- IngentaConnect
- INSPEC
- Library Literature Online
- LISTA (Library, Information Science and Technology Abstracts)
- Oxford University Press journals
- SAGE Journals Online
- ScienceDirect
- Social Science Citations Index
- Web of Knowledge

Key journals which were regularly scanned for relevant articles using the databases listed above included (but were not limited to):

- Harvard Business Review
- Industry and Higher Education
- The Learning Organization
- Journal of Documentation
- The International Journal of Technology Management
- The Journal of Knowledge Management
- The Journal of Information Science
- The Journal of Knowledge and Process Management
- European Business Review

- Business Process Management Journal
- Journal of Business Strategy
- European Journal of Innovation Management
- Strategic Direction
- Journal of Intellectual Capital
- Technovation

3.5 Preliminary Study

Prior to the commencement of the pilot study, a preliminary study was conducted. This stage of the research had a number of objectives. It aimed to identify the key issues in relation to the innovation process in conjunction with published literature prior to the main study; to establish the existence of a common language used by players within the innovation process; to determine what the commonly used terms were within that language; and lastly to develop an understanding of the meanings of those terms. The purpose of the preliminary study was to broaden understanding of the innovation process from the perspective of practitioners, and thus to ensure that any questions posited within the research were couched in terms understandable to the participants. Additionally, the thirteen interviews (details of which are provided in the next section) were used to determine if the issues identified within the body of literature and the perspectives presented on innovation and the innovation process itself bore a resemblance to those provided by practitioners.

This stage can be seen to have contributed to the researcher's overall understanding of innovation and the innovation process, and aided (along with the ongoing search and review of the literature) in the formalization of the research area, the research questions raised, and the aims and objectives of the research.

While perhaps less obvious that in the other stages of the research process, the preliminary study also adopted a postmodern perspective. Rather than attempting to unify the various perspectives taken by the interviewees into an overarching theory of the innovation process (or grand narrative as Lyotard proposes) the preliminary study also aimed to identify the variety of the different perspectives provided by the interviewees.

The preliminary study was conducted using semi-structured interviews as the method of data collection. The validity of the use of semi-structured interviews at this stage in the research process is emphasised by Saunders et al (1997, p.212) who state that: 'Semi-structured and in depth, or non-standardised, interviews are used in qualitative research in order to conduct exploratory discussions to reveal and understand not only the 'what' and the 'how', but also to place more emphasis on exploring the 'why'.'

Interviewing is one of the four methods of gathering information typically used by qualitative researchers (Marshall and Rossman, 2005, p.97). Often described using Kahn and Cannell's definition as 'a conversation with a purpose' (Kahn and Cannell, 1957, p.149), interviews have a number of specific strengths. Perhaps most notably, interviews are a useful method of obtaining large amounts of data quickly. However, interviews are also reliant on the willingness of the participants to share information which could then be used in conjunction with the information gathered during the course of the literature search in order to develop a better understanding of both the theory and the practice of the innovation process. Semi-structured interviews were selected as the method of data collection for this stage of the research as they use a more flexible structure than structured interviews, and as such as useful for exploring topics which may not be completely familiar to the interviewer, while at the same time providing a general structure in terms of the subject coverage of the interview.

This flexible structure also means that additional questions which may not have been included in the interview schedule can be included in an impromptu way during the interview: 'In semi-structured interviews the researcher will have a list of themes and questions to be covered, although these may vary from interview to interview. This means that you may omit some questions in particular interviews given the specific organisational context which is encountered in relation to the research topic. The order of questions may also be varied depending on the flow of the conversation' (Saunders et al, 1997, p.212). In addition to this, their style is more conversational than structured interviews and as such they tend to put interviewees at their ease and consequently make them more willing to share information.

Several typologies of interviews have been developed. Powney and Watts (from Robson, 1993) suggest that interviews may be distinguished by the level of control exercised by the interviewer. In their typology, respondent interviews rely on the interviewer maintaining a high level of control during the interview in order to steer the discussion towards relevant topics. Informant interviews, also known as non-directive interviews, rely on the interviewer allowing the person interviewed to guide themselves with the aim that they will provide valuable information which may otherwise be omitted in a highly structured interview.

For the purposes of the preliminary study it was considered appropriate to adopt the informant interview format in order to elicit data on a broad range of issues pertinent to the innovation process.

One of the key considerations when selecting the sample group of interviewees for the preliminary study was to identify a group with established links in which the concept of the innovation process was both understood and employed by the different players. Creswell (1997, p.118) states that the 'purposeful selection of participants represents a key decision point in a qualitative study.' A variety of strategies for purposeful sampling have been proposed. Miles and Huberman (1994, p.28) for example identify sixteen strategies within their typology. It is important to note that these strategies as not necessarily mutually exclusive and a sampling strategy may encompass more than one of these. The two types of sampling used within this stage of the research were snowball and convenience sampling. Miles and Huberman (1994, p.28) state that the purpose of snowball (or chain sampling) is that it 'identifies cases of interest from people who know people who know what cases are information-rich'.

In addition to identifying an appropriate sample group through purposeful sampling, practical factors affecting the research in relation to time and distance were also considered. The timescale for the research meant that an appropriate group be located in a relatively short period of time. An initial interview was conducted with the special projects officer of the Aberdeen City council who had established a group made up of representatives from a consortium of organizations involved (in different ways and to different degrees) with the process of innovation in the broadest sense of the term. The project officer not only established the group, but also managed the administration of the group. This interview sought to establish whether there would be interest in the group in taking part in the interviews, and also to seek the approval of the group co-ordinator in order to illicit a higher rate of positive responses (through snowball sampling), rather than simply contact the group unannounced.

The location of the group also lent itself well to ensuring that a representative sample of players from the group could be interviewed in a short period of time. In addition to these factors, there was an additional benefit in using a group centred around Aberdeen. Aberdeen has a well-established research base, with two universities, one further education college and several renowned research bodies such as The Macaulay Institute and the Rowatt Research Institute operating in close proximity. Each of the twelve organisations whose employees were members of the group were send letters explaining the project, and inviting them to interview stating that this was being conducted with the prior knowledge and consent of the group organiser. The letters also included a fax return form for fast responses, as well as full contact details (including an email address) and a stamped addressed envelope in order to try to illicit as high a rate of return as possible.

Nine representatives from eight organisations were initially interviewed. In all cases the interviews were conducted one-to one with the key organisational contact of the group, and in their own organisation at a time specified by themselves. In all instances, the interviews lasted approximately one hour with the shortest lasting approximately fifty minutes, and the longest lasting one and a quarter hours. All the interviewees consented to the interviews being recorded. These were then transcribed following the interview. Notes were however also taken during the course of the interviews. The respondents were assured that their anonymity would be maintained if they so wished. The interview schedule was also updated over the course of the eight interviews where problems were identified concerning the clarity of the questions. This was however not related to the content of the questions themselves.

The interviews covered a range of topics which were largely directed by the interviewees themselves. Generally however most of the interviews addressed the following topics:

- What the interviewees understood by the term ‘innovation’
- The relationships between innovation, commercialisation and technology transfer
- The role of their organisation within the innovation process
- Their personal role within the innovation process
- The implications of participation within the innovation process
- Collaboration between actors/players within the innovation process

In order to provide more consideration to the industry element of the research and to identify innovation issues specific to the UK oil and gas industry itself, an additional four interviews were also conducted with representatives of organisations involved with the industry. The organisations sampled from within the UK oil and gas industry represented a sample of public and private sector organisations with an involvement in the innovation process. In relation to the classification of actors within the technological innovation process used within this research the interviewees represented one end user organisation, a technology provider, and two enabling organisations.

3.6 Main Study: Research Design

3.6.1 Identification of Pilot and Sample Groups

Having identified the research problem through the literature search and review (see Section 3.4), and the preliminary study (see section 3.5), the study then moved on to the identification of an appropriate data sample. Using the standard set of actors within the innovation process (providers, enablers and end users) and the context of the UK upstream oil and gas industry (as identified in Appendix IV: Contextual Framework), the research approach continued to utilise purposeful sampling as a technique for selecting an appropriate sample frame. Fowler (1993, p.11) defines the sample frame as 'the set of people that has a chance to be selected, given the sampling approach that is chosen. Statistically speaking, a sample only can be representative of the population included in the sample frame.' Effectively therefore, the sample frame is a reflection of the population. The more accurate the sample frame, the closer it will be to giving an accurate representation of the population. Fowler (1993, p.19) states that 'How well a sample represents a population depends on the sample frame, the sample size, and the specific design of the selection procedures.'

The validity of this approach is emphasised by Saunders et al (1997, p.125) who suggest that sampling is a valid alternative to a census (an analysis of data from every member of a group) in a number of circumstances:

- 'it would be impractical for you to survey the entire population;
- your budget constraints prevent a survey of the entire population;
- your time constraints prevent a survey of the entire population;
- you have collected all the data but need the results quickly.'

Given the vast number of both providers of technological innovations and end users of those innovations within the UK upstream oil and gas industry and the comparatively very small number of enablers, a rationale was adopted to utilise snowball sampling based around an organisation with a significant role in enabling the technological innovation process (identified in Chapter 2 and above in the preliminary study). This rationale can be seen to reflect the circumstances identified by Saunders et al above. The Industry Technology Facilitator (ITF) was selected as an appropriate organisation which could act to identify, as Creswell, (1997, p.119) proposes 'cases of interest from people who know people who know what cases are information-rich' as well as its key role in enabling technological innovation in the upstream UK oil and gas industry.

In consultation with ITF, nine technology providers were identified from ITF's 'Blue Book', a status report compendium on joint industry projects (JIPs). These projects are grouped into a number of categories:

- Facilities Projects
- Subsurface Projects
- Wells Projects
- Production Projects
- Application Projects

3.6.2 Development of the Interview Process

Within the context of social science, narratives are increasingly being viewed as valuable sources of qualitative data (Elliott, 2005). Hinchman and Hinchman define narratives within the context of social science as '...discourses with a clear sequential order that connect events in a meaningful way for a definite audience and thus offers insights about the world and/or people's experiences of it' (1997, p.xvi). Typically however, the use of narratives from a methodological perspective has focussed on the analysis of written narratives rather than how those narratives may be elicited (Lieblich et al, 1998). This may in part be due to the proliferation of narratives themselves as Riessman suggests: 'Locating narratives of personal experience for analysis is not difficult. They are ubiquitous in everyday life. We can all think of a conversation when someone told in exquisite detail what she said, what he said, what happened next – a recapitulation of every nuance of a moment that had special meaning for her' (1993, p.2).

The ubiquity of stories and narratives is acknowledged by many writers in the field (e.g. Jameson, 1991; Lyotard, 1984; Barthes, 1966; 1981) and is further emphasised by Barthes: '...narrative is present in every age, in every place, in every society;' (Barthes, 1966, cited in Reissman, 2008, p.4). Although this may appear to be a somewhat trivial point, the ubiquity of the narrative is an indicating factor of its societal importance. Narrative then can be seen to be a tool in its own right which helps society to make sense of itself in some way. Stories and narratives act as ways of making meaning within given and understood structures.

This can be seen to be potentially beneficial and detrimental to the research process itself, by on one hand allowing the researcher a large degree of flexibility as to how narratives are gathered, and on the other hand little guidance as to the potential effectiveness of the techniques used. Indeed as Czarniawska suggests: ‘The narrative device does not predetermine in any sense how the material is to be constructed or collected. In more traditional parlance, there is no obvious connection between the narrative approach and any specific method of study’ (1998, p.19).

‘So natural is the impulse to narrate’ (White, 1981, p.4) that it is the social nature of storytelling which then impacts on the role of the researcher using narratives as sources of data. The focus of the researcher is then placed on the analysis of the narratives in accordance with the views of Lieblich et al (1998), and less on attempting to draw out the narratives from the respondents. However, where the researcher does have an important role in eliciting narratives is in identifying a subject appropriate to the respondents.

The interview process developed and applied within main study utilised a deliberately open approach to collect narratives appropriate to determining the forms and types of knowledge used by the different actors within the innovation process and also the knowledge-based processes present, in accordance with the aims and objectives set for the research. Thus, interviewees were asked to relate a story of how a technological innovation had been developed from its conception to its eventual production and application, with particular reference to the role of knowledge within the process.

3.6.3 The Role of Piloting within the Main Study

Having secured the participation of ITF (identified in Appendix IV and within the preliminary study earlier in this chapter), a pilot study was conducted, the purpose of which was to trial the approach which would be used within the main study. Specifically, the pilot study tested the use of narrative interviews as a method of data collection and the analytical frameworks (described in Sections 3.6.5 and 3.6.6) for analysing the data collected through the narrative interviews. Although perhaps obvious, it is worth noting the importance of a pilot study particularly in research of this type where the development and application of a novel methodological approach is central.

An individual was identified using snowball sampling who had experience working within enabling organisations within the UK upstream oil and gas industry. The pilot study used narrative interviews to gather data from this player, and continued to employ snowball sampling to identify a technology provider and end user who could participate in the pilot study. Although several technology providers and end users were identified, none of the end users approached were willing to participate in the pilot stage of the research (due either to time constraints or sensitivities regarding the technologies they were employing), and consequently only the technology provider participated in addition to the enabler. Despite this, the size of the sample of the pilot study was considered to be appropriate given the relatively small size of the sample for the research itself.

Due to considerations of time and geography the interview with the enabler was conducted face-to-face, whereas the interview with the technology provider was conducted via telephone. Although less satisfactory than face-to-face interviews due to the fact that there is no opportunity to observe more informal communication such as body language, Creswell (1997, p.124) states that the key merit of a telephone interview is that it 'providers the best source of information when the researcher does not have direct access to individuals'. Both interviews were recorded with the permission of the interviewees.

Although both interviews yielded good quality data (and in fact the interview with the representative from the enabling organisations actually yielded two stories of technological innovations) which met the objectives of the research, it is interesting to note that the quantity of data gained from the telephone interview was notably less than the face-to-face interview. Both interviews were then transcribed, and an NVIVO project (described below) created to store and analyse the data. The pilot showed that the use of narrative interviews as a method for data collection in this context proved to be valid by providing data appropriate to achieving the objectives set for the research. In addition, the analytical frameworks (described in detail below) proved to be robust enough to enable the data to be coded and analysed successfully in order to address the third, fifth and sixth research questions.

3.6.4 Conducting the First Set of Main Interviews

Initially nine technology providers were approached to take part in the research project however three chose not to participate for reasons identified below. During the interviews with the technology providers, the providers were asked to identify contacts in the end user organisations who had been involved with the project. Although this had not been identified as a potential problem within the pilot study, a number of the providers were unwilling to provide this information either due to reasons of confidentiality, or in order to avoid disclosing which organisations were sponsoring or using their technologies.

As stated in Section 3.6.2, interviewees were asked to relate a story of how a technological innovation had been developed from its conception to its eventual production and application with particular reference to the role of knowledge within the process. With the exception of one interview which was conducted via telephone due to the interviewee's location, all interviews were conducted at the interviewees' place of work. In all cases, the interviews took place in either the interviewees' offices, or a private meeting room to avoid potential distractions and to ensure good sound quality. All the interviews were recorded using a digital recorder with the permission of the interviewees, which was granted in each case. The interviews varied in length with the shortest (the interview which was conducted via telephone) lasting approximately half an hour, and the longest lasting almost two hours.

Given both the methodological approach taken as well as (perhaps more significantly) the topics of the stories gained from the project participants, it was essential to address a number of ethical issues within the scope of this project. Creswell states that 'regardless of the tradition of enquiry, a qualitative researcher faces many ethical issues that surface during data collection in the field and in analysis and dissemination of qualitative reports' (Creswell, 1997, p.132).

From the outset of the main study, one of the most immediate problems was the involvement of the participants. Despite using snowball sampling, which it was considered would yield a potentially larger sample of actors within the innovation process in the UK upstream oil and gas industry, a number of potential participants did not wish to take part in the project as they felt that what they would be discussing would be too commercially sensitive to share with their competitors. Initially the methodology sought to collate narratives relating to the development of specific technological innovations. By taking the perspectives of the providers, enablers and end users of a specific technology, a 'compound' multi-linear narrative could subsequently be developed which related to the development of that technology.

By taking multiple perspectives on the development of a singular technology, the methodology sought to provide a postmodernist perspective by showing that in effect there was no 'grand narrative' or universal truth in the development of that technology, and that despite there being multiple perspectives on the development of that technology and consequently multiple stories, that each individual perspective or narrative regarding the development of that technology each gave a uniquely valuable insight into the development of that technology which collectively added to the understanding not only of how that specific technology was developed but also of how this specific context added to the more generic understanding of the innovation process as a whole.

However, it became clear in early interviews that this approach was (in this specific context) inapplicable due to concerns on the part of both the technology providers and the end users. As a number of the innovations had not yet reached market, several of the providers were concerned that they might be revealing commercially sensitive information relating to the nature of their technology which might then be used by a potential competitor. Additionally, some providers were unwilling to reveal who the potential users of the technology were in case this subsequently revealed to potential competitors not only who these organizations were (and so make approaches to them themselves in order to sell their own technologies), but also what their technology issues were. Several of the technology providers were also unwilling to reveal who the potential end users may be in case this breached the trust of the end users, and subsequently breached an existing or potential contract.

Because of these factors a broader perspective on the research was taken in order to address both of these concerns. The methodology was subsequently adapted such that the individual perspectives of the providers, enablers and end users were grouped together not in relation to the development of specific technologies, but by the role of the narrators within the innovation process. This not only avoided the need for the different actors within the process to reveal their relationship with each other and also with the potential role of the technology, but also gave a more appropriate postmodern perceptive by according the role of the individual actors with their role within the innovation process generally rather than in relation to the development of a specific technology.

Although some of the technology providers did provide names of their end users with whom they had been involved during the development of their tools or processes, several were unwilling to pass on this information. In order to address this problem, ITF were approached again at a face-to-face meeting and asked for an additional list of potential project participants, this time consisting of technology end users who were member companies of ITF. Of the thirteen companies who are members of ITF, seven chose to participate in the study. By taking this approach, the technology providers did not have to identify who their users were, yet ironically the end users were (in most cases) extremely open during their interviews about the projects they engaged in with the providers. Including ITF then, fourteen interviews were conducted in the first stage of the project with representatives from one enabling organisation (ITF), seven end users, and six technology providers. Further information regarding the end users and technology providers is provided in Appendix I: Sample Organisations.

3.6.4.1 Ethical Issues

The topic of technological innovation itself can be seen to be one which naturally lends itself to ethical problems. Given the relatively small group of actors within the sample frame (i.e. those organisations who acted as providers or end users of technology who interfaced using ITF) many of the participants were already well aware of each others technological offerings (if they were providers) or the technology strategies of their potential competitors (if they were end users). The key issue for the technology providers seemed to relate to having more informal information captured about the actual process of innovation rather than details of the technologies themselves, much of which was already publicly available. In the case of the end users, several potential participants seemed unwilling to share information about their strategies without the approval from their senior managers, and as such did not feel it was appropriate to share any information for which they may subsequently be penalised in some way.

One of the most obvious ethical issues which is encountered in any qualitative study is that of anonymity. In recruiting interviewees to the study, they were provided with full information about the purpose of the study, what would be involved, and reassurance that any data would be reported anonymously. Creswell (1997, p.93) states that: ‘A researcher protects the anonymity of the informants, for example, by assigning numbers of aliases to individuals.’

In relation to this study, each organisation which participated was given a unique identifying code. Furthermore, the individuals in the organisations and the projects they discussed were also given unique codes. Although this goes some way towards protecting the anonymity of the participants, their organisations and their technologies, the methodological approach makes it difficult to completely protect identities. Narrative technique by nature encourages participants to convey information in a way which is relatively natural to most people, and because of this, the transcripts of each interview were sent back to the participants for their approval before they were used in any way within the context of the project. In addition to this, interviewees were assured that the audio data collected from the interviews, and any transcribed material would be stored in a secure location for the duration of the research and would be destroyed on its conclusion.

For those who did participate, a number of different levels of approval for the usage of the information were evident. Some participants went through their transcripts in great detail, even in some cases heavily editing what they had said. There can be seen to be a number of different reasons why participants did this. In one case, the participant’s first language was not English and he felt that (following the interview) he did not converse well enough and needed an opportunity to ‘clean up’ the information grammatically and syntactically. Another participant became aware of the pauses inserted in his transcript, and asked for these to be removed.

Most significantly however, several participants edited their interviews to remove any material they felt to be commercially sensitive. This is perhaps understandable enough as several of the technologies discussed, although anonymised as stated above, were still not in production. Although this scenario is not ideal from a researcher’s perspective, it is important to acknowledge the wishes of participants in studies where they are discussing topics which could potentially affect their organisations and even their livelihoods.

3.6.5 Development of Knowledge Processes, Type and Form Template

A critical element of any narrative research is the development of the analytical approach (Lieblich et al, 1998; Riessman, 1993; Czarniawska, 1998). Lieblich et al (1998) identify two independent dimensions which may be considered in relation to the analysis of non fiction narratives: holistic versus categorical approaches; and content versus form: ‘The first dimension refers to the unit of analysis, whether an utterance or section abstracted from a complete text or the narrative as a whole’ (Lieblich et al, 1998, p.12).

In the context of this stage of the research, a categorical-content approach is clearly in evidence. Categorical-content approach (or content analysis as it is often referred) was adopted in order to develop an analytical approach which could be used to identify the knowledge processes, types and forms of knowledge present within the technological innovation process, and thus address the fifth and six research questions raised by this research. The validity of this approach within the context of this research is supported by both the use of nonfiction narratives (Branigan, 2001) as sources of data, and the emphasis of this approach on identifying specific themes or topics within the narratives: ‘categories of the studied topic are defined, and separate utterances of the text are extracted, classified, and gathered into these categories/groups' (Lieblich et al, 1998, p.13). This approach is often considered to be a classic approach to narrative research (Riesmann, 1993), although there can be seen to be a wide range of ways of applying it. Lieblich et al (1998) identify four steps in the application of this approach which are common to the different variations, and have been applied within this research. To highlight the application of this approach, the text from one of the narrative interviews conducted as part of the pilot study has been used to illustrate each stage of the process.

3.6.5.1 Selection of the Subtext

'On the basis of a research question or hypothesis, all the relevant sections of a text are marked and assembled to form a new file or subtext, which may be seen as the content universe of the area studied' (Lieblich et al, 1998, p.112). It is important to note that only the relevant sections of the text are included within this content universe. Although the amount of relevant text will vary from narrative to narrative, this step ensures that only material which is pertinent to the question or hypothesis is included.

From the fourteen interviews conducted within this stage of the research, the content of any interview which did not directly relate to the development of a technological innovation was removed from the transcriptions. The purpose of this was to ensure the purity of the content universe, and also to avoid the inclusion on unnecessary content in the narrative system described below. Using the example of one of the pilot interviews, by removing irrelevant text, the length of the story was reduced from sixty four sentences to fifty four sentences.

3.6.5.2 Definition of the Content Categories

Lieblich et al posit that '...categories are various themes or perspectives that cut across the selected subtext and provide a means of classifying its units – whether words, sentences, or groups of sentences' (Lieblich et al, 1998, p.113). The content categories used within this stage of the research were defined by drawing on the literature as it related to the knowledge-based processes (identified in Section 2.5.1); and the forms and types of knowledge (identified in Section 2.3) to produce the following structure:

Knowledge-based Processes	Knowledge Types		Knowledge Forms
Knowledge Acquisition and Learning (DiBella and Nevis, 1998; Wiig, 1993; McKenzie and van Winkelen, 2004; Burnett et al, 2004; Polanyi, 1966; Argyris, 1977; Senge, 1990)	Declarative Knowledge (Alavi and Leidner, 2001)	Knowledge About (Alavi and Leidner, 2001) Know What (Lundvall and Johnson, 1994; Sveiby) Know That (Sveiby, 2002) Know Who (Lundvall and Johnson, 1994)	Explicit (Polanyi, 1966; Nonaka and Takeuchi, 1995)
Knowledge Transfer and Dissemination (DiBella and Nevis, 1998; Wiig, 1993; McKenzie and van Winkelen, 2004; Burnett et al, 2004; Nonaka and Takeuchi, 1995)	Causal Knowledge (Alavi and Leidner, 2001)	Know Why (Alavi and Leidner, 2001; Lundvall and Johnson, 1994)	Tacit (Polanyi, 1966; Nonaka and Takeuchi, 1995)
Knowledge Storage and Maintenance (Wiig, 1993; McKenzie and van Winkelen, 2004; Burnett et al, 2004)	Procedural Knowledge (Alavi and Leidne, 2001)	Know How (Alavi and Leidner, 2001; Lundvall and Johnson, 1994; Sveiby, 2002)	Implicit (Nickols, 2000)
Knowledge Application and Exploitation (DiBella and Nevis, 1998; Wiig, 1993; McKenzie and van Winkelen, 2004; Burnett et al, 2004)	Conditional Knowledge (Alavi and Leidner, 2001)	Know When (Alavi and Leidner, 2001)	
Knowledge Valuation and Measurement (Wiig, 1993; McKenzie and van Winkelen, 2004; Burnett et al, 2004)	Relational Knowledge (Alavi and Leidner, 2001)	Know With (Alavi and Leidner, 2001)	
Knowledge Creation (Wiig, 1993; Burnett et al, 2004; Nonaka and Takeuchi, 1995)			

Table 13: Knowledge-based Content Categories

The table shows the knowledge-based processes, and the types and forms of knowledge together with the main theorists who proposed each. By adopting a 'general to specific' approach to the data, these content categories form the basis of three analytical 'passes' used to identify the knowledge-based processes, and the forms and types of knowledge present within those processes for each actor. For example, Knowledge Acquisition and Learning is identified as a process within a story, and then the forms and types of knowledge present within that process are identified:

Knowledge Acquisition and Learning (DiBella and Nevis, 1998) (Wiig, 1993) (McKenzie and van Winkelen, 2004) (Burnett et al, 2004) (Polanyi, 1966) (Argyris, 1977) (Senge, 1990)		
Declarative Knowledge (Alavi and Leidner, 2001)	Knowledge About (Alavi and Leidner, 2001) Know What (Lundvall and Johnson, 1994; Sveiby) Know That (Sveiby, 2002) Know Who (Lundvall and Johnson, 1994)	Explicit (Polanyi, 1966; Nonaka and Takeuchi, 1995)
Causal Knowledge (Alavi and Leidner, 2001)	Know Why (Alavi and Leidner, 2001; Lundvall and Johnson, 1994)	Tacit (Polanyi, 1966; Nonaka and Takeuchi, 1995)
Procedural Knowledge (Alavi and Leidne, 2001)	Know How (Alavi and Leidner, 2001; Lundvall and Johnson, 1994; Sveiby, 2002)	
Conditional Knowledge (Alavi and Leidner, 2001)	Know When (Alavi and Leidner, 2001)	
Relational Knowledge (Alavi and Leidner, 2001)	Know With (Alavi and Leidner, 2001)	
Declarative Knowledge (Alavi and Leidner, 2001)	Knowledge About (Alavi and Leidner, 2001) Know What (Lundvall and Johnson, 1994; Sveiby) Know That (Sveiby, 2002) Know Who (Lundvall and Johnson, 1994)	Explicit (Polanyi, 1966; Nonaka and Takeuchi, 1995)

Table 14: Knowledge-based Processes, Forms and Types

The importance of coding in the process of qualitative research is noted by Strauss (1987, p.27) who contends that: 'Coding...is an essential procedure. Any researcher who wishes to become proficient at doing qualitative analysis must learn to code well and easily. The excellence of the research rests in large part on the excellence of the coding.' These categories were also used to provide a coding structure using the data analysis software NVivo 2.0.

NVivo 2.0 was used as a software environment within which to apply the content categories identified above, to sort the material into those categories (described in section 3.6.5.3) and to draw conclusions from the results (3.6.5.4). NVivo allows for the storing and manipulation of qualitative data, and allows users to apply codes to the data. Creswell (1997, p.155) suggests that methodological discussions relating to the application of computer programs in analysis are often neglected by authors, and this may in part be due to a further suggestion by Creswell that there is a need to clearly establish a link between the use of these programs to analyse text and traditions of enquiry. However a variety of tools are being used increasingly in narrative methodologies in order to thematically 'map' stories. Boje (2001, p.65) states that 'both NUD*IST and NVivo as well as Ethnograph allow the qualitative researcher to collect a rich array of text fragments from interviews, observations literature and archival review.'

Despite the issue of linkage identified by Creswell (1997) above, he also identifies a number of benefits of using these types of program. Pertinent to this research, these can be seen to include:

- 'The computer program provides an organized storage "file" system so that the research can quickly and easily locate material and store it in one place
- The computer program helps a researcher locate material easily, whether this material is an idea, a statement, a phrase, or a word.
- A computer program "forces" the researcher to look at the database line for line and think about the meaning of each sentence and idea' (Creswell, 1997, p.156).

Regardless of these clear benefits, Creswell goes on to identify a number of disadvantages in the use of computer programs. In addition to obvious disadvantages such as the cost, maintenance and time to learn how to use such programs, Creswell also identifies an issue relating to the analysis of the material itself: 'Computer programs may take the place of a careful analysis of the material. As such, they should not be a substitute for a close reading of the material to obtain a sense of the whole; they should be an adjunctive procedure in the analytical process' (Creswell, 1997, p.156). This was an important consideration in relation to this research project. The software was used to support the analytical process rather than acting as an analytical tool in its own right.

3.6.5.3 Sorting the Material into categories

Having selected the relevant subtext within the content universe and defined the content categories from the relevant literature as it relates to the specific research questions, the material was then sorted into those categories: ‘At this stage, separate sentences or utterances are assigned to relevant categories’ (Lieblich et al, 1998, p.113).

The length of the different units of material can be seen to vary greatly from narrative to narrative. In some instances one sentence may be relevant to a category, whereas in others entire paragraphs may be relevant. It is important to acknowledge that the use of content analysis within narratives often means that more lengthy extracts of the verbatim text are presented to avoid disrupting both the ‘flow’ of the story, and also to ensure that the inherent value of the content is not lost in its relation to the categories (Riessman, 1993; Czarniawska, 1998).

The following examples draw on one of the pilot interviews to show the relationships between three of the knowledge-based processes (knowledge acquisition and learning; knowledge creation; and knowledge valuation and measurement) and the forms and types of knowledge present within those processes as content categories:

“And actually as it happens, the answer if you like, or the Eureka bit came about as a consequence of the conversation with a guy from [End User_1] at the time (he is no longer with BP). He was heavily involved in drilling all the new wells in Kuwait and sorting out the wells in [Area_4] following the Gulf War. Here was a big exercise and I asked him the question: “What is the cost of drilling a hole onshore as against drilling a hole offshore?” I can’t remember the figures off the top of my head but you are talking about a tenth of the cost. And we thought: “this is interesting, why is it so much cheaper?”

This quote shows the acquisition of declarative knowledge by the actor from an actor within an end user organisation. It can be seen to be based on the tacit procedural knowledge of the actor from the end user organisation, and precedes the process of knowledge creation:

“The Eureka moment was, well actually there is no bloody water involved if you are drilling onshore. Therefore, all the support systems like the big floating rig, etc do not exist. So we thought “shit, is it possibly to design something that can get over the problem that is created by the bloody water?” That lead after a lot of back of fag packet-type thoughts to the concept

of putting an entire drilling system straight on the seabed that would be supported by a surface vessel, but that surface vessel could be a relatively simplistic sort of surface vessel."

This quote illustrates the creation of new knowledge in terms of the explicit formalisation of an opportunity for technological innovation. However in this instance, as there is a lack of procedural knowledge on the part of the actor from the enabling organisation, he is reliant on the application of tacit declarative and procedural knowledge of an actor from a technology provider to determine the feasibility of the proposed technology:

"So we [Enabler_11] then involved a company called [Provider_20] which is owned by a guy called [Contact_15] who has a record for being quite innovative in terms of new business systems. We put the idea to him to test really whether technically this was sensible, were there any real, sort of genuine pit stops. The answer after a couple of months was "No we can't." There might be some engineering to do, but actually we can't find anything which would really stop this happening."

The quote shows the high degree of tacit procedural and declarative knowledge of Contact_15, and emphasises the importance of these types of knowledge in determining the technical feasibility of technological innovations. This subsequently can be seen to impact on the value of the knowledge itself embedded in a potential new technology:

"As we looked more and more into it, it was very obvious that from a capital plus point of view it wasn't just cheaper, it would be a hell of a lot cheaper. So we were right, we now know that this is technically achievable and yes it is going to have an enormous impact on cost. You are talking about something that has the capital, you know the capital for the equipment of the whole system which is going to be about 12 million pounds as compared with something in excess of a billion dollars."

From the knowledge acquired from the other actors involved in the innovation process, the actor from the enabling organisation can be seen to have acquired declarative knowledge regarding the technical feasibility of the technology and the potential financial impact of its application.

Lieblich et al (1998) note that this stage is open to some degree of interpretation on the part of the researcher. However as they rightly note: 'interpretation does not mean absolute freedom for speculation and intuition. Rather intuitive processes are recruited in the service of comprehension, which examines the basis for intuiting and should test it repeatedly against the narrative material...While traditional research methods provide researchers with systematic inferential processes, usually based on statistics, narrative work requires self-awareness and self-discipline in the ongoing examination of the text against interpretation, and vice versa' (1998, p.10). In effect then, the body of stories taken from the actors provides an ongoing process of interpretation.

3.6.5.4 Drawing Conclusions from the results

The last stage in the analytical approach is to draw conclusions from the results. Lieblich et al propose that this may be done in one of two ways. Firstly though a quantitative approach in which occurrences of specific themes are calculated or (as in the case of this research) 'the contents collected in each category can be used descriptively to formulate a picture of the content universe in certain groups of people or cultures' (Lieblich et al, 1998, p.113).

As can be seen from the examples above the content categories can be applied successfully to the primary data to determine the knowledge-based processes, and the forms and types of knowledge present within a process of innovation. The examples provided also illustrate the importance of the various actors at different stages within the innovation process according to their role (provider, enabler and end user), and also highlights the relationships between the knowledge-based processes. This then provides an opportunity to examine the relationships between the primary data and prior research in relation to knowledge processes, forms and types and the innovation process, and subsequently to determine if new insights can be gleaned from these perspectives.

3.6.6 Development of Narrative/SSM Analytical Template

Following on from the development and application of the analytical template described in Section 3.6.5, this stage of the research process describes the development of an additional analytical template employing elements of Soft Systems Methodology (SSM) and narrative schema. In line with Lieblich et al's four dimensions of narrative analysis, this stage can be seen to be a form of categorical form analysis (1998, p.17) or structural analysis which places emphasis on the structure of narratives, rather than their content. This section will present the underpinning theories behind each element of the analytical template, and discuss how these elements have been brought together into one analytical approach.

Prior to discussing the development and application of this template, it is important to acknowledge the purpose of this stage and sequencing of the application of these templates. This template has a significantly different purpose from the previous template. While the previous template was developed and applied to conduct a form of content analysis appropriate to narratives in order to determine the knowledge-based processes, types and forms present within the primary data, the narrative/SSM template acts as a form of structural analysis and is applied within several ways. It acts as a framework for the deconstruction of complete oral stories gathered from actors within the innovation process into component elements or categories and the subsequent construction of written narratives, thus acting as a structure to codify and subsequently transfer explicit knowledge (Dixon, 2000) using the narrative system discussed below.

Although this may at first appear to be a simple issue of transcription, Riessman (1993) emphasises the importance of this process within narrative research: ‘Transforming spoken language into a written text is now taken quite seriously because thoughtful investigators no longer assume the transparency of language. Qualitative researchers now ask themselves how detailed transcriptions should be...Not simply technical questions, these seemingly mundane choices of what to include and how to arrange and display the text have serious implications for how a reader will understand the narrative’ (1993, p.12).

The sequence of the application of these analytical templates (first content analysis the structural analysis) is important as this stage affects the structure of the narratives, whereas the application of the previous template does not. Oral stories do not necessarily follow the formalised structure of narratives (Czarniawska, 1998; Riessman, 1993), therefore the narrative/SSM template allows for the identification of individual narrative elements wherever they exist within a story, and their relocation into a linear narrative structure.

3.6.6.1 Selection of the Subtext

The selection of the subtext within this stage applies the same principles which were presented in Section 3.6.5.1. Indeed once the relevant sections of the subtext were selected to inhabit the content universe and the irrelevant sections (i.e. those parts of the text which did not relate to the technological innovation process) omitted, the same subtext were used as the basis for both the content and structural analysis, as can be seen from the following diagram:

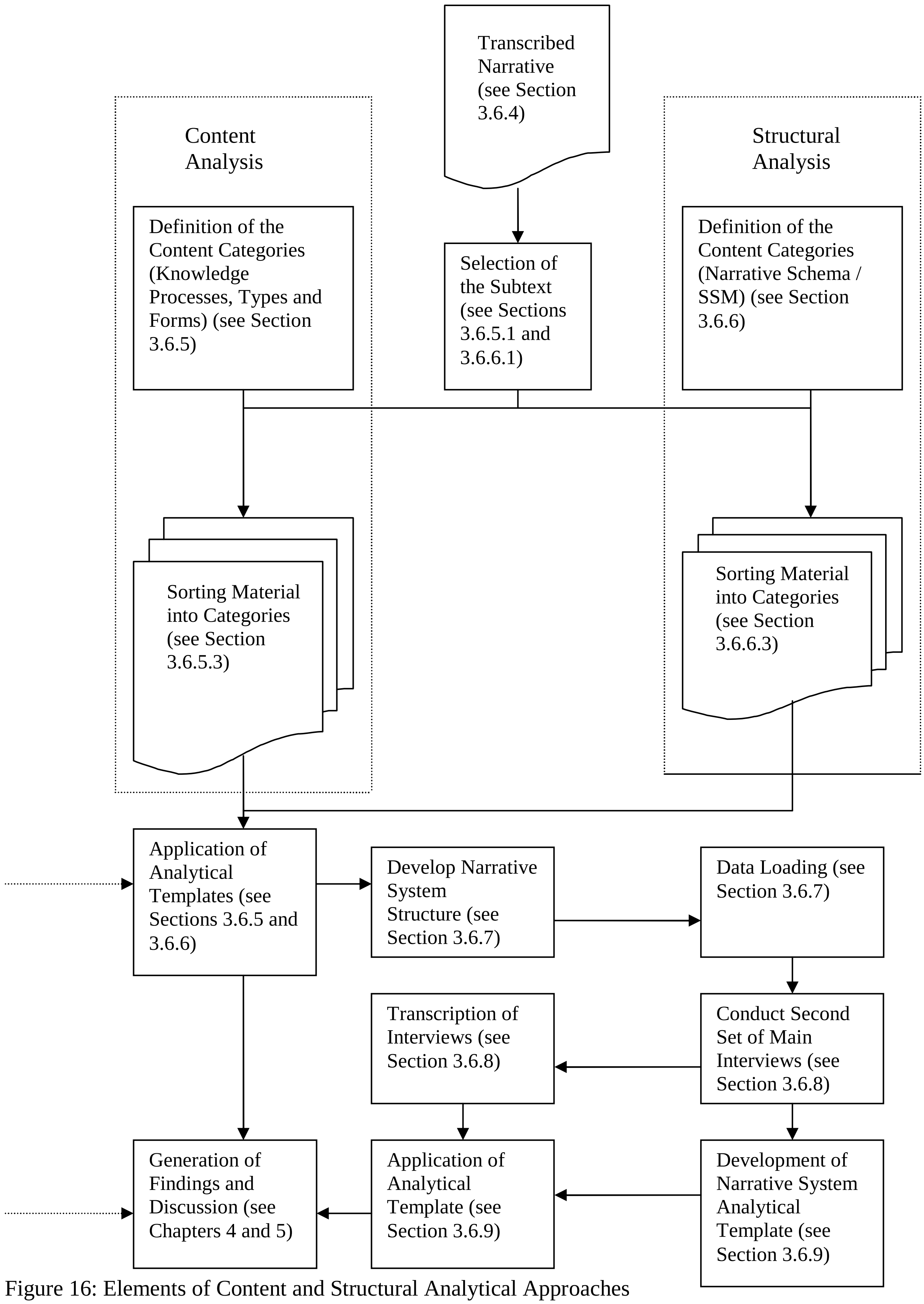

Figure 16: Elements of Content and Structural Analytical Approaches

3.6.6.2 Definition of the Content Categories

A variety of analytical approaches have been proposed in relation to the structure of narratives. Perhaps the most commonly acknowledged example is the structural analysis of folktales by Propp (1968): ‘In this type, the structure or formal organization of a folkloristic text is described following the chronological order of the linear sequence of elements in the text as reported from an informant. Thus if a tale consists of elements A to Z, the structure of the tale is delineated in terms of this same sequence’ (Propp, 1968, p.xi). Propp proposes a method by which folktales may be classified according to their structural features. However, as Propp himself acknowledges, this classification does not lend itself readily to other types of tale. The use then of Propp’s classification to analyse factual narrative (or narrative nonfiction as Branigan (2001) refers to it) as opposed to folk fiction can be seen to be inappropriate within the context of this research.

In his examination of narrative theory and structure, Todorov (1982) proposes that all narratives consist of a situation going through a five stage transformation, those stages being a state of equilibrium at the outset; a disruption of the equilibrium by some action; a recognition that there has been a disruption; an attempt to repair the disruption; and lastly a reinstatement of the initial equilibrium. An arguably more sophisticated form of narrative transformation is presented by Labov (1972), and it is one which is most commonly used by narrative researchers (Riessman, 1993).

An adaptation of Labov’s work is provided by Branigan (2001) who identifies narrative schema as consisting of the following elements: an *abstract* (which is a title or compact summary of the situation which is to follow); an *orientation* (which is a description of the present state of affairs) while an *exposition* gives information about past events; an *initiating event (which* alters the present state of affairs); a *goal* (which is a statement of intention or an emotional response to an initiating event by a protagonist); a *complicating action* (linked to an antagonist) which arises as a consequence of the initiating event and presents an obstacle to the attainment of the goal; the climax and *resolution* end the conflict between goals and obstacles and establish a new equilibrium or state of affairs; the *epilogue* is the moral lesson implicit in the history of these events and may include explicit character reactions to the resolution; and the *narration* seeks to justify implicitly or explicitly why the narrator is competent and credible in arranging and reporting these events and why the events are worthy of attention: ‘In other words, how is it possible to possess the knowledge and why should it be possessed’ (Branigan, 2001, p.18)?

Specifically it is this form of narrative schema which together with Soft Systems Methodology provides the template for structural analysis described in this section. Developed by Checkland (1981) in the late 1960s, SSM is a methodology designed to be used in ill-defined or 'fuzzy' problems. The work can be seen as a reaction to the hard systems methodologies (HSM) which Checkland felt were overly reliant on being able to clearly define a problem. A critical element within SSM is the use of root definitions. Checkland and Scholes (1995, p. 36) define a root definition as: 'a system to do X by Y in order to achieve Z'.

There can be seen to be a number of justifying factors for its inclusion within the methodological approach within this research. Ho and Sculli (1994, p.48) argue that SSM is based on a number of specific characteristics of managerial problems:

- There are many equally legitimate perceptions of the reality of the problem.
- Each viewpoint of reality is restrictive or incomplete and can be challenged by alternative viewpoints.
- Debate and discussion among the interested parties will lead to a more comprehensive understanding of the problem situation.
- The discussion and debate will also tend to "move" the parties towards some agreed feasible solution that should alleviate the problem situation.

In relation to this research, the first and second characteristics are particularly pertinent. The first characteristic can be seen to acknowledge an almost postmodern perspective in which there is in effect no 'grand narrative' but instead a number of differing perspectives each of which is equally valid (Lyotard, 1984). Related to this is the second characteristic which allows for each perspective to be challenged by the others, and this is reflected in the engagement of the participants with the narrative system.

Like all research methodologies, SSM is being constantly refined, improved and updated, and has already been through two iterations (the 1975 model, and the late-1980s model). As such, it can be seen to be flexible enough for adaptation to specific purposes. Checkland and Scholes (1995) identified both the core method of SSM as well as a number of potential variants which could potentially include its integration with narrative schema:

Core method within SSM	**Possible elaborations**
Name relevant systems, both ‘primary task’ and ‘issue-based’	Use metaphors to examine relationships in the situation, or other aspects of the situation
Formulate root definitions meeting the CATWOE requirements; think of the schema: a system to do *X* by *Y* in order to achieve *Z*	(See (b) below)
Build models based on one T, ‘7±2’ activities in an operational system, and a monitoring and control system using criteria for efficacy, efficiency and effectiveness	(a) Use more criteria than the ‘3 Es’ (e.g. add Ethicality, Elegance) (b) Use more complex model structures entailing several Ts in various relationships (e.g. parasite/host or syndicate)
Make the links in the model indicators of which activities are contingent upon which other activities	Develop flow versions of the model (abstract or concrete flows), or use this to decide on dependencies.

Table 15: The core method of the SSM logic-driven stream of thinking and some variants [Source: Derived from Checkland and Scholes (1995, p.42)]

The purpose of providing this table is principally to emphasise the flexible nature of SSM. However specific to this research, Checkland and Scholes (1995) suggest that T (the transformation process) may be: ‘supplemented with other considerations of a broader nature if it seems appropriate in a particular field’ (1995, p.42). Within the context of the innovation process, T (identified as a process of transformation) can be seen to be the process of transformation of a technological innovation from an initial idea through to its development, application and diffusion (Rothwell, 1992).

From the above it can be seen that an inherent feature of both SSM and narrative schema is their flexibility. They are both methods which can be used to meaningfully describe a variety of different types of situations and contexts. In order to develop a methodological approach which unified these techniques it was necessary to identify how they could be integrated at an elemental level which linked the key components of SSM with narrative schema to create an analytical template. As the output of the analysis was to be provided in the story form, rather than in the ‘rich picture’ form which is commonly used in SSM, narrative schema is used to provide the basis of the methodology with the elements of a root definition of SSM being ‘mapped’ onto it. Checkland and Scholes (1995) provide the following definitions for each of the elements used within a root definition:

C	Customers	the victims or beneficiaries of T
A	Actors	those who would do T
T	Transformation Process	the conversion of input to output
W	Weltanschauung	the worldview which makes this T meaningful in context
O	Owner(s)	those who could stop T
E	Environmental Constraints	elements outside the system which it takes as given

Table 16: CATWOE Elements [Source: Derived from Checkland (1981)]

Using the narrative structure identified previously by Branigan (2001), the CATWOE elements were mapped onto narrative schema to produce the following analytical template which integrates elements of both:

Integrated Methodology elements	**Narrative schema elements**	**CATWOE elements**
Element 1: abstract and prologue	Abstract and prologue	
Element 2: orientation	Orientation	Customers, Actors, Owners
Element 3: exposition	Exposition	Weltanschaaung, Environmental constraints
Element 4: initiating event	Initiating event	
Element 5: goal	Goal	
Element 6: complicating action	Complicating action	
Element 7: resolution	Resolution	
Element 8: epilogue	Epilogue	

Table 17: Integrated elements of Narrative Schema and SSM

Based on the definitions of the elements of narrative schema provided by Branigan (2001), the following definitions of the new elements were produced which again incorporate the CATWOE elements of root definition:

1. An *abstract* or prologue providing a title and summary of the situation to follow
2. An *orientation* providing a description of the present state of affairs (including place, time, customers, actors and owners of the process),
3. An *exposition* providing information about past events which have bearing on the present including environmental constraints and Weltanschauung.
4. An *initiating event* altering the present state of affairs.
5. A *goal* providing a statement of intention or an emotional response to an initiating event by a protagonist.
6. A *complicating action* (linked to an antagonist) arising as a consequence of the initiating event and presenting an obstacle to the attainment of the goal.

7. A climax and *resolution* ending the conflict between goals and obstacles and establishing a new equilibrium or state of affairs.
8. An *epilogue* providing the moral lesson implicit in the history of the events and (potentially) including explicit character reactions to the resolution.

The integrated methodology encapsulates all the elements of both SSM and narrative schema. Although this may look like T (transformation process) of SSM has been overlooked, by its nature the process is implicit in the whole story as it moves from beginning to end. The elements of the integrated methodology provide a structure for the analysis and subsequent re-presentation of the data within the narrative system described below.

3.6.6.3 Sorting the Material into categories

The transcription of each interview was imported from Microsoft Word into NVivo 2.0 and ascribed an appropriate name in relation to the role of each actor such as End User_1, Provider_2, Enabler_1, and so on. Codes (described as 'nodes' in NVivo) comprising the integrated elements of narrative schema and SSM were applied to each interview. For example, using one of the stories employed within the pilot study, the following narrative structure is present within the transcription of the beginning of the oral story:

Abstract and prologue: *"[Project_13] is a novel way of drilling exploration holes.'"*

Exposition: *"It was really evolved as a consequence of what was a fairly glaring business demand which was to somehow reduce, dramatically, if possible the cost of drilling an exploration hole. And the reason that we arrived at that conclusion, if you like, was the team of CMPT had been looking at average drilling failure rates across the North Sea purely from an academic point of view, because we were just interested in what they were. At the time that we started thinking about it drilling failure rates were more than sixty per cent. So sixty per cent of every hole drilled produced a well which, for some reason not commercially viable, it was either dry or didn't flow properly or whatever. But it was technically a failure. This represents an enormous amount of money; many millions of dollars have been spent on each hole."*

Initiating Event: *"So we started to look at ways this might be done more cost effectively. We did look at it certainly philosophically in terms of what happens when you drill a hole, if you require data from which you can make analysis to determine whether the structure, the geological structure is likely to contain hydrocarbon or not."*

Following these three elements, the story went on using the subsequent structure:

- Complicating Action
- Goal
- Initiating Event
- Goal
- Complicating Action
- Resolution
- Complicating Action
- Resolution
- Complicating Action
- Epilogue

This shows that while the narrative elements exist within oral stories, they do not necessarily follow the linear structure of narrative schema. Thus the narrative/SSM template provides a tool to deconstruct oral stories and reassemble them into a more linear format, as shown in this example using the pilot story above:

Oral Story Elements	**Written Narrative Elements**
Abstract and Prologue	Abstract and Prologue
Exposition	(Element 2: Orientation)
Initial Event	Element 3: exposition
Goal	Element 4: initiating event
Initiating Event	Element 5: goal
Complicating Action	Element 6: complicating action
Goal	Element 7: resolution
Complicating Action	Element 8: epilogue
Resolution	
Complicating Action	
Resolution	
Complicating Action	
Epilogue	

Table 18: Oral Story and Written Narrative Elements

Each of the elements included in the oral story is then reordered following the sequence of the narrative/SSM template. Within the above example, an orientation (a description of the present state of affairs including place, time, customers, actors and owners of the process) was not provided, and so does not constitute an element of the written narrative. This ensures that the content of the written narrative accurately follows that of the oral stories as told by the project participants, and also follows the written narrative structure.

3.6.6.4 Drawing Conclusions from the results

The application of this analytical template deviates from the processes described in Sections 3.6.5 in that conclusions are not drawn from the restructured narratives. Instead, the restructured material is sorted into the content categories which form the structure for the narrative system described below.

3.6.7 Develop Narrative System Structure

Specifically, the development of the narrative system aimed to address the fourth research question: How can the actors' explicit knowledge of the innovation process be codified and transferred? Not only does this stage of the research process aim to practically address the fourth research question by developing an internet-based system in which explicit knowledge may be codified and transferred (Dixon, 2000), it also further supports the postmodern and post-structuralist perspectives adopted at a philosophical level throughout the research (Kristeva, 1986; Barthes, 1981). From a post-structuralist perspective, hypetertextual systems (such as the one discussed here) provide environments in which the readers may make conscious choices as to how they navigate through the narratives (Landow, 1997).

In line with the fourth research question, the main function of the system was to provide an environment in which the explicit knowledge of the project participants could be stored, codified in the form of narratives using the narrative/SSM template, and transferred through the users' engagement with the narratives. Screenshots of the website are provided in Appendix III.

An internet site (http://www.innovation-narratives.co.uk) was developed using PHP (a scripting language suitable for internet-based development work which may be embedded in Hypertext Markup Language - HTML) and a MySQL database. Having collated, deconstructed and reconstructed the data using the narrative/SSM template in NVivo 2.0, the restructured narratives were loaded into the MySQL database.

The website was designed to allow users to create stories/narratives within the Narrative Schema/SSM structure and to also to select and read different sections of any or all of the narratives within the system. Each interviewee was sent a username and password to allow them into the website, and a user guide (provided in Appendix II). The website was password protected to further protect the anonymity of the interviewees and their technologies, and also to avoid data being added to the database which was not relevant to the research.

When a user input a valid username and password, they were presented with a menu system with several options:

- Write - Add a new story to the System
- Read - Read an existing story
- Edit - Edit one of your own stories
- Compare - Compare stories or sections of stories

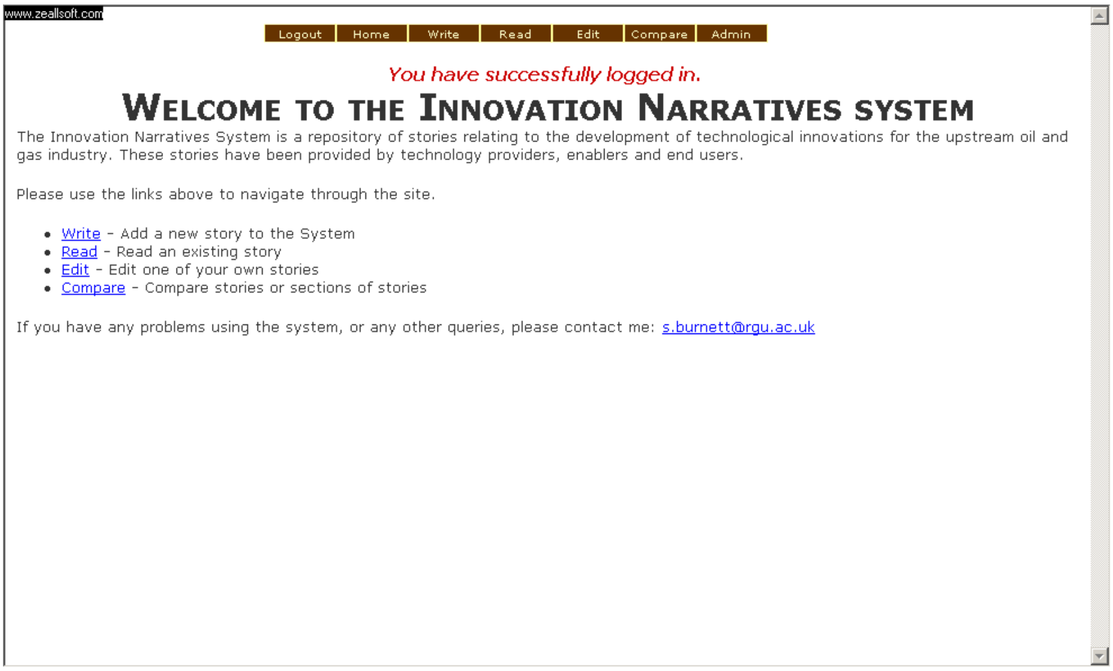

Figure 17: Front Page of Narrative System

By clicking on the ‘Write’ menu item, users were brought to a new page which allowed them to create a new story. The user decided what type of author role they wish to write under (based on their role within the innovation process: enabler, provider or end user), and gave the story a title as the stories in the database were recognised by ‘Title’ and ‘Author’ fields). Text boxes were provided for users to complete corresponding to each of the elements of the Narrative Schema/SSM structure described above. Users were able to input section of their story into each corresponding section on screen and then save the text into the database. Users were also able to view any stories stored in the database which are available to them.

Additionally, using the ‘Edit’ menu option, users could go back to a previously authored story and modify it however they saw fit.

When a story was first written or when it was re-edited, the story became ‘unapproved’. This meant that until the content is approved by an administrative user of the system it could not be viewed by anyone other than the author. When multiple stories were approved and available, any user could go in and compare any of these stories they wished to view.

There were a number of options within the ‘compare’ function. The user had to first choose whether they wished to compare complete stories (i.e. viewing every section of each story chosen), or whether they wanted to select the individual sections (i.e. those elements of the narrative identified using the narrative/SSM template) that they wished to view.

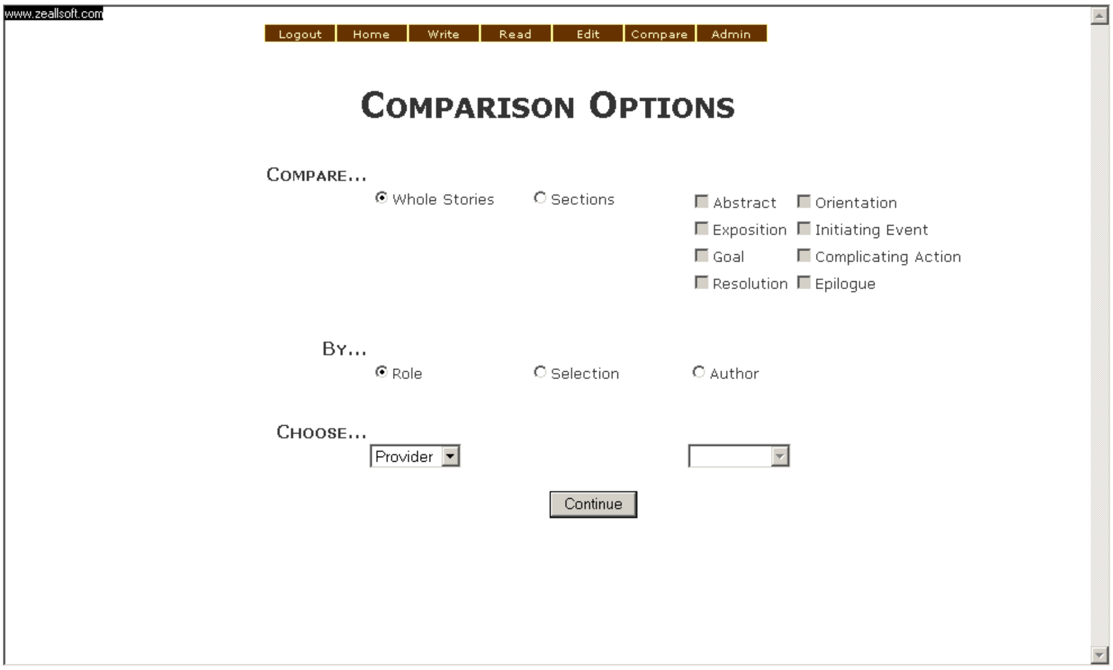

Figure 18: Narrative Comparison Options

The users had to decide if they wanted to choose narratives by the same author (i.e. the same interviewee), if they wanted to choose narratives by authors writing in the same author role (technology provider, enabler or end user), or if they want to select individual stories themselves from a list of all the narratives stored within the database. If they decided on one of the first two options, they had to then filter this further by choosing either the author or author role of the narratives they wished to view. Finally on the following screen, they had to choose the individual narratives available to them based upon their previous choices. Once this was done, the narratives were presented in fixed-width alternating-background-colour columns with each section title shown on the left of the screen.

In addition to the ‘standard’ users described above, an administrative user function was created. This provided access to a number of additional features unavailable to standard users. When any narrative was created or edited, the administrative user had to first use the Approve tool on that narrative before it could be compared to other narratives in the system. This allowed for greater control of content of the database. This was done by selecting the narrative the user wishes to authorise from a list of all narrative awaiting approval. The narrative was then displayed for the user to read, at the end of which they had the option to release the narrative so that it could be viewed by other users.

The administrative user also has the ability to create new users within the website. To do this, a form was created which the administrative user may complete. This form specified if a new user was an administrative user or a ‘standard’ user, provided an opportunity to select a username and password for the new user in addition to completing personal details such as name, organisation, and job title). The username and password could then be sent to a new user via email to allow them to access the content of the website.

3.6.8 Narrative System Interviews

Once all the transcribed interviews (for which permission was given) were loaded on to the narrative system, the project participants were emailed with a user name and password to access the website and were asked to use the website to read, compare and write narratives. Interviewees were given six weeks to use the website before being contacted again to ask for their participation in a second interview. This stage was to determine the extent to which the fourth objective set for the research (How can the actors’ explicit knowledge of the innovation process be codified and transferred?) had been achieved.

In addition, the interviews acted as an opportunity to add to and reinforce the data from the participants in relation to the role of knowledge within the innovation process gathered from the first set of interviews, and provided an additional opportunity for the interviewees to validate the content and structure of the system. As such, the second set of interviews provided an opportunity for ‘inward triangulation’ of the participants’ own data in the form of written narratives. The purpose of triangulation in qualitative research is to increase the credibility and validity of the results. According to O’Donoghue and Punch triangulation is a method of cross-checking data from multiple sources to search for regularities in the research data (2004, p.78). In this instance, the interviews were able to validate their own data in the form of the narratives contained within the system, as well as examining the data provided by other interviewees.

All of the participants who had participated in the first part of the research were contacted to ask for their participation in a second interview. Of the fourteen interviewees who had participated in the first part of the research, seven agreed to participate. A number of factors limited the size of this sample. Notably, the upstream oil and gas industry is characterised by the movement of individuals between roles, organisations and locations. Of the seven interviewees who did not participate in the second interview, four had left the organisations for which they worked in the first phase of the research, two had changed roles within their own organisations and were no longer involved in technological innovation (and consequently felt unwilling to participate further in the research), and one interviewee was unable to participate due to time constraints. The interviewees thus represented the same enabling organisation, three end user organisations, and three technology providers.

Unlike the first interview which used narrative interviewing to encourage the interviewees to recount a story relating to the development of a particular technology, the second interview used a semi-structured interview technique. Burns (2000, p.424) states that: ‘Rather than having a specific interview schedule or none at all, an interview guide may be developed for some parts of the study in which, without fixed wording or fixed ordering of questions, a direction is given to the interview so that the content focuses on the crucial issues of the study.’ Narrative interviewing was not considered to be a relevant technique for this element of the research as the interviewees were not being asked to recount an event. In relation to Burns’ view above, an interview guide was prepared which identified three areas for the interviewees to consider.

Firstly, the interviewees were asked to consider what new knowledge they had gained about the technological innovation process in the UK upstream oil and gas industry from their engagement with the narrative system. This issue was included within the interview to determine the usefulness of the system as a vehicle to transfer knowledge. Secondly, they were asked what they thought about structure and functionality of the system. This issue was included to determine the value of the structure of the system through its use of the narrative/SSM template. Lastly, the interviewees were asked to reflect on the usefulness and value of the system in relation to its content (i.e. narratives relating to the technological innovation process).

In line with the first part of the research, all the interviews were recorded using a digital recorder, and were again conducted in the interviewee's place of work. Once the interviews had been transcribed and anonymised, they were emailed to the interviewees for their approval prior to the data being analysed. Again, the interviewees were assured that the data would be stored in a secure location, and that the audio recordings and the transcriptions would be destroyed on completion of the research.

3.6.9 Development and Application of Analytical Template

Given the scope and content of the first topic raised within the second set of interviews, the same analytical template was used as described in Section 3.6.5. This was to be used to determine what knowledge of the innovation process had been acquired by the interviewees as it related to the knowledge processes, types and forms present within that process.

However in addition, another coding structure was used in relation to the narrative system itself. This coding structure was developed through more detailed examination of the data collected using a grounded theory approach (Glaser and Strauss, 1967). Broadly, the coding addressed issues relating to the content, structure and interface of the website (with more specific issues being included in relation to each of these areas. The following table describes the codes used:

System Content	**System Structure and Interface**
Comprehension	Interface
Scope	Comparing
Value	Writing
Anonymity	Reading

Table 19: Definition of Content Categories (Part 2)

NVivo 2.0 was used again to store the data in the form of transcribed interviews (which were approved by the interviewees prior to analysis) and to code the data using the content categories identified above. The transcriptions from the second set of interviews were included in the same NVivo project which was created for the first set of interviews.

3.7 Summary

This chapter has aimed to detail the methodological approaches used within the research project and has drawn on the philosophical perspectives underpinning the methodological approaches, and the practice and theory of social science. This chapter can be seen to relate directly to the third objective set for the research: To develop a methodological approach by which knowledge-based processes, and forms and types of knowledge within the innovation process may be examined. The narrative system developed can also be seen to address the fourth objective (to develop a tool which may be used to store, structure and transfer the explicit knowledge of actors relating to the process of technological innovation). In addition the analytical framework based around the knowledge processes and the types and forms of knowledge is applied to achieve the fifth and sixth objectives set for the research: to develop generalisable typologies and characterisations of the information and knowledge that is the content of various knowledge-based processes between actors; to identify the knowledge-based processes which exist within the process of technological innovation. The results of the application of this methodological approach are discussed within the next two chapters which provide the finding and discussion relating to the research.

CHAPTER FOUR: FINDINGS

‘If you have knowledge, let others light their candles with it.’ (Winston Churchill)

4.1 Introduction

The purpose of this chapter is to present the findings relating to the data gathered from the narrative and semi-structured interviews and analysed using the analytical templates discussed in the previous chapter in Sections 3.6.5 and 3.6.9. Within this chapter the first set of findings derived from the narrative interviews (presented in Section 4.2) are structured firstly according to the roles of the actors interviewed, then by the knowledge-based processes, and lastly by the forms and types of knowledge present within those processes. The purpose of this structure is to show the various perspectives and emphases placed on the different knowledge processes, forms and types by the different groups of actors (see Figure 19 below), and the views of the actors in relation to the roles undertaken by the actors in support of these processes. To provide further clarification of the findings, key findings as they pertain to each group of actors are provided in Sections 4.2.1.7, 4.2.2.7, and 4.2.3.7.

Section 4.3 presents the findings derived from the semi-structured interviews (see Section 3.6.8) as they pertain to the interviewees’ perspectives on the technological innovation process following their engagement with the system, and the participants’ perspectives on their engagement with the narrative system (developed in order to address the sixth objective set for the research) itself. The purpose of these interviews was to determine if the narrative system could be used as a tool to successfully store and transfer the codified explicit knowledge of the interviewees in the form of narratives, and to determine whether the actors were influenced by exposure to the explicit knowledge of other actors thus addressing the sixth research question raised for the research, and adding to the findings of the research in relation to the role of knowledge within the innovation process.

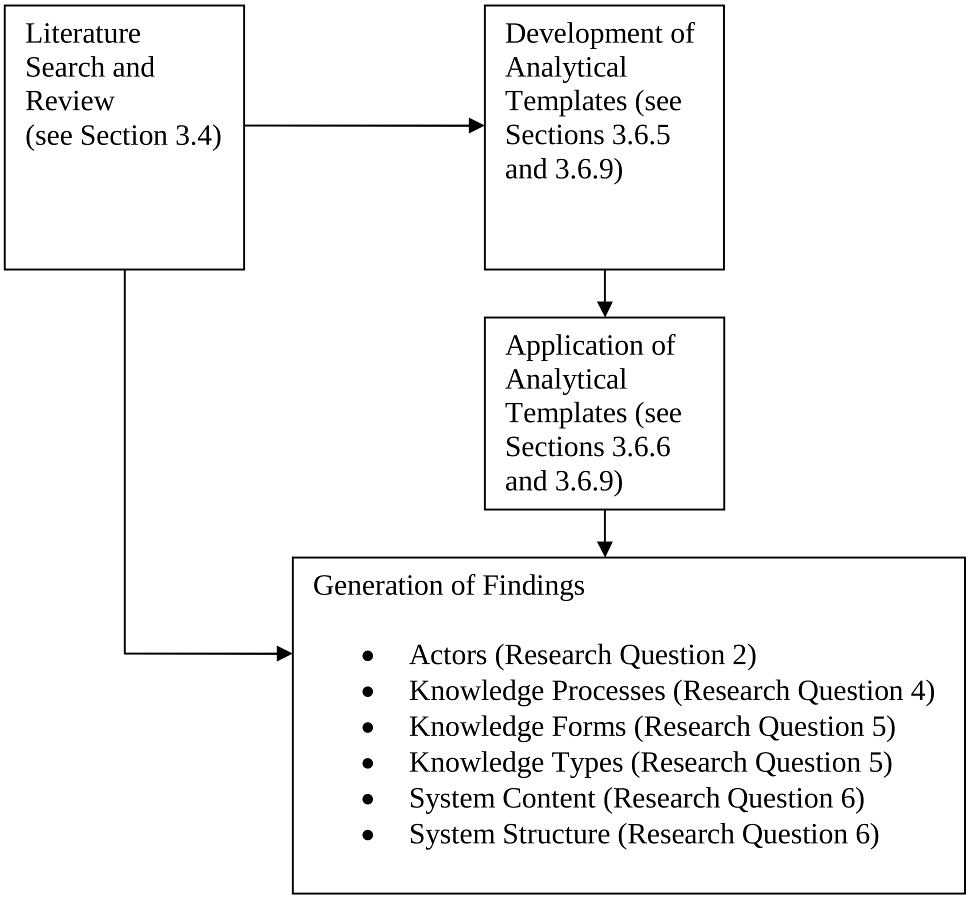

Figure 19: Generation of Findings

The findings presented within Section 4.2 address the following research questions:

Research Question 2: Who are the actors within the technological innovation process in the UK upstream oil and gas industry, what are their roles, and what is the nature of their knowledge-based interactions?

Research Question 4: What knowledge-based processes occur within the technological innovation process, how do they manifest themselves, and what is their significance within this process?

Research Question 5: What forms and types of knowledge are utilised within the technological innovation process, how do they manifest themselves, and what is their significance within this process?

The findings presented in Section 4.3 also contribute to addressing research questions 2, 4 and 5 and also address the following research question:

Research Question 6: Are the actors within the technological innovation process influenced by exposure to the explicit knowledge of other actors, and if so how can this knowledge be codified and transferred?

With regard to the presentation of the findings, quotes from participants can be seen to be relatively lengthy. The length of the quotes used is largely dependent on the length of the parts of the narratives used as units of analysis (Landow, 1992); however the quotes also illustrate the importance of the narrative itself as a framework used by the participants to recount incidents relevant to the research (Jovchelovitch and Bauer, 2000).

4.2 Findings: Part 1

4.2.1 Enabling Organisation

The representative from the enabling organisation was keen to indicate from the outset the unique nature of each technological development process:

"One of the things that we find that is very, very different when it comes to commercialization and field trials, is it's not a case of one size fitting all. It's quite the opposite. Each individual prospect when it comes to a trial phase becomes a very unique proposition, not just a commercial proposition. The whole dynamics of the mechanics of how we do things on a company by company basis from a point of view of a developer, but also from a company by company basis from the point of view of the end user or the sponsor, it very much has to be tailored uniquely to each individual set of circumstances." (Contact_1, Enabler_1)

This perspective provided by the enabler supports the postmodernist view of the demise of the grand narrative as presented by Lyotard (1984). The interviewee shows an understanding of both the different roles played by the different actors within the innovation process of the UK upstream oil and gas industry (with particular reference to the specific role of the enabling organisation), as well as the concomitant perspectives associated with these roles. As such, the interviewee acknowledges that there is no unifying view or perspective which acts to amalgamate the perspectives provided by the various actors.

4.2.1.1 Knowledge Acquisition and Learning

From the literature review, knowledge acquisition and learning refers to how individuals and groups may acquire knowledge through learning from a variety of different types of sources and in different ways, as well as acquiring knowledge embedded in information (Argyris, 1977; Senge, 1990). Although acquiring specific types of knowledge was clearly in evidence (for example declarative 'know who' type knowledge), it was less clear from the enabler how or from where this knowledge is obtained:

"We're trying to help technology and if it so means we're finding potential sponsors or investors to do that then that's part of the game." (Contact_1, Enabler_1)

Enabler_1 states that the organisation seeks out innovative solutions, as well as identifying the technology needs of its member organisations (ITF, 2008). Although this presents a formal proactive process for identifying innovations for Enabler_1's member organisations, the proposal process utilised by Enabler_1 is in effect a reactive process. Initially the proposal process utilised by Enabler_1 allows any organisation to submit a proposal which obviously raises an awareness of both 'know who' and 'know what' types of declarative knowledge (Alavi and Leidner, 2001), and provides an opportunity for Enabler_1 to acquire new types of knowledge: Enabler_1 is made aware of who is conducting work in specific areas, as well as the nature of that work.

Specifically in relation to the acquisition of 'know what' type knowledge, the process is more apparent once the proposals have moved on to a commercialisation phase and can clearly be seen to be based on managing the relationships with the technology providers and the end users in a relatively informal way:

"We've got an ongoing dial up with each of our members and I'll pick up the phone and have a chat with them now and again. It might be informal chat or it might be a pointed chat. "Have you thought about this? Are you aware that these guys are doing something?" Or [Contact_10] or [Contact_11] or whoever might phone me up and say "We've heard that this is coming up. Is there any way for us to get involved with that?" So it's more of a networking relationship rather than "let's review this at the end of next month and make some formal decisions."" (Contact_1, Enabler_1)

However the interviewee also acknowledges that this approach is one which he personally finds valuable, rather than following a formal relationship management process:

"We tend to work very much in the informal network type dial-up but again that's very much my style, and I find more value in keeping abreast of where a company is even though they are delivering projects." (Contact_1, Enabler_1)

Although the enabling organisation can be seen to have developed and applies a formal process for the submission and evaluation of proposals, once this process is underway it is the responsibility of the individuals within the organisation to manage the ongoing relationships between both the technology providers and the end user organisations. As acknowledged by the interviewee, this is clearly a personal approach rather than a formalised way of working. The management of relationship can be seen to affect both what knowledge is acquired and how it is acquired. This point was also made by the interviewee in relation to the end user member companies:

"One of the things that we've got to be careful with is if we start chasing things and progressing and expediting directly we'll probably get a cold shoulder, whereas if you maintain a relationship with things that are going on in the marketplace that are not directly relevant to you asking for money you might actually get a hint about whether money is available behind the scenes. So we have to create mechanisms and means of having a conversation without always asking for money and that means that we have to use intelligence. Where does the intelligence come from? Well, it comes from the companies that we are trying to support in the first place." (Contact_1, Enabler_1)

This view also acts to illustrate the close relationship which exists between the processes of knowledge acquisition and knowledge transfer (Dixon, 2000).

4.2.1.2 Knowledge Transfer and Dissemination

The transfer and dissemination of knowledge between the different players within the innovation process can be seen to be reliant on the ability of the enabling organisation to provide opportunities for the players to engage with each other:

"My role is to try and create an environment where there is opportunity for networking across the contacts that we have for those looking for support and for those with money to support." (Contact_1, Enabler_1)

The interviewee acknowledges the importance of creating and maintaining a network which spans both the technology providers as well as the end users. However, there is also a realisation that sensitivities concerning the transfer of knowledge within the network must be taken into consideration:

"But to create as big a scene as that, it's not as stark as going begging for money all the time so we have to be an information flow process. We don't give away confidential information. I mean I get told sensitive things about companies because people trust me, so I'm not going to say "Company X, Y or Z - they've been drawn back by the bank and they are not going to be given the borrowings that they need to keep training, so they will have to do some payoffs." I'm not going to tell people that, but at the same token there's actually some good stuff going on here and they've just delivered a project and actually it's working quite well. You use that sort of information to flow in one direction and you get the information flowing back at you." (Contact_1, Enabler_1)

Within this context then, the importance of knowledge transfer is not only in the sharing of declarative ('know who' and 'know what') knowledge with the potential beneficiaries of that knowledge, but also in the appreciation of what declarative knowledge *not* to share, which may influence whether or not a new technology is developed and subsequently applied.

Knowledge transfer in the form of inter-organisational networking (as identified within the literature review) can be seen to be a key activity, specifically in relation to the development of joint industry projects (JIPs). In this instance, the importance of identifying lead players to support the project is evident:

"...companies are willing to take a punt for a small amount of money on a distributed fund JIP, but they will always look for a lead through a [End User_1] or [End User_4] or[End User_6] or whatever to be the lead player within that. So we are always looking for the corner-stone guys, and we do have to work those guys to get the trust and knowledge built up. We tend to find if we do get [End User_4],[End User_1], or [End User_6] as the corner stone to be the first adopters to say "we'll come into this JIP if you can find other players."" (Contact_1, Enabler_1)

An awareness of the important role played by Enabler_1 in the matching of technology needs and the subsequent transfer of knowledge relating to those needs is also identified by the technology providers:

"I think there is a symbiotic relationship between the function of [Enabler_1], which I see as people that are capable of understanding the technology, linking the people with some technology solutions to the people with technology demands. You've got the operators there not necessarily knowing or being able to access some of the solutions to the problems they've got. You've got people in the service sector particularly with a set of solutions but can't find the opportunities, and I've found that [Enabler_1] have been very good at connecting those organizations together. I think that probably is an underlying fundamental strategy of theirs. They are taking their funding from a number of operators who are interested in that connection, and feed occurring continuously and perhaps one in ten or two in ten of those technologies go on to have significant commercial success. But if ten aren't passed through, then the two will never be discovered." (Contact_10, Provider_2)

Both from the perspective of the enabling organisation itself as well as the technology providers, Enabler_1 act as a conduit of knowledge between and within the technology providers and the end users. The types of knowledge transferred between these groups can be seen to be varied, both generally in relation to the generic knowledge needs of the two groups, as well as the specific needs of the particular actors. Enabler_1 acts to make the technology providers aware of the specific technology needs and priorities of actors within the end user community which may be fulfilled by the technology providers ('know what'). It acts to raise awareness of the providers ('know who' knowledge), the technologies they have developed ('know what'), and in addition their procedural knowledge in the form of competencies ('know how') not only in relation to their ability to create technological solutions for the end users, but also additional related factors such as their ability to manage the commercialisation process. Additionally, Enabler_1 acts to share declarative 'know what' and 'know who' knowledge and acts as a catalyst for knowledge transfer within the end user community.

4.2.1.3 Knowledge Storage and Maintenance

Although the formal storage of knowledge and its subsequent maintenance is not explicitly acknowledged by the interviewee, the proposal process used by Enabler_1 can be seen to be a process not only by which explicit knowledge relating to technological development is acquired, but also forms the basis for a storage process:

"We've got a bank of folk that we know of and always invite in, and the operators will tell us from that session who we've missed that we perhaps should invite, and they may say "Invite [Provider_2] in. We know about [Provider_2]." We'll put that call for proposals out, and invite them to propose something against that from which we end up with forty, fifty, whatever number of proposals coming in, all independently but all within a period of time. There's an opening date and closing date for proposals to come in. We sift through them, making sure that they're not completely taking the Mickey and they're old projects with a new badge on them, but on the basis that they are valid projects. We send all those to the operators who package them in a particular format." (Contact_1, Enabler_1)

The enabling organisation can clearly be seen to have in place a formalised process by which explicit declarative knowledge of particular technologies ('know what') and technological capabilities ('know how') are gathered and then subsequently filtered:

"We ask those folks to tell us whether or not this is a project. First of all, "Are you interested in the technology?" The second thing we ask them is: "Are you in a position or do you have the enthusiasm to do something about it to actually support this technology, either yourself or some sort of a collaboration?"" (Contact_1, Enabler_1)

Enabler_1 appears to take a structured and critical approach to its role in engaging with the technology end users. Not only does the organisation acknowledge the importance of the technology itself, but also the potential relationships between the providers and the end users.

4.2.1.4 Knowledge Creation

Although the whole function of the enabling organisation is to support and facilitate the innovation process, the interviewee was keen to emphasise that the enabling organisation is not involved in the creative process either in terms of the development of the technologies themselves, or the opportunities which may arise by which those technologies are developed:

"The biggest danger we have is that people tend to create a business plan and that dominates the running of the business. The problem is life is not like a business plan. Opportunities arise whether you like it or not. There is a trial that might happen that has probably been looking for a trial for three years now, and it might just happen. I knew about it before I came to [Enabler_1], but you know folks have got to realize when the right time happens, it happens.

[Enabler_1] aren't going to force anything to happen. We are a facilitator. We aren't a creator of opportunities. We facilitate opportunities, and the thing that we have to look for is opportunities and they will come along and hit us on the back of the head sometimes." (Contact_1, Enabler_1)

The role of the enabling organisation is then to support the innovation process, in most cases (as is discussed later in this chapter) after the initial conceptual and developmental work (i.e. knowledge creation) has been completed. Notably, Contact_1 emphasises the declarative knowledge of opportunities ('know what') for the technology providers.

4.2.1.5 Knowledge Application and Exploitation

The focus of Enabler_1's role can clearly be seen to relate to the application of their tacit and explicit declarative ('know what') knowledge both of their members' technology needs, as well as their knowledge of the capabilities, expertise (procedural 'know how' knowledge) and declarative ('know what') knowledge of technologies of the technology providers.

The relationship between the enabling organisation and the technology providers appears to relate at some levels to aiding the providers in their customer orientation. The organisation appears to apply both 'know what' and 'know who' types of knowledge within their proposal process. Specifically, the application of the tacit knowledge of the organisation relating to declarative ('know what'), procedural ('know how'), conditional ('know when') types of knowledge can be seen to apply to the evaluation stage of the proposal process. An additional type of conditional knowledge (which is not identified by either Alavi and Leidner, 2001, or Lundvall and Johnson, 1994) is also in evidence within this process: 'know where'. This is a significant finding for the research, and is discussed in more detail in Chapters 5 and 6.

These types of knowledge are applied by the enabling organisation in order both to identify technologies which may be of benefit to their member organisations and, concomitantly, to filter out those that are not. However this process was not explicitly identified as a function by the enabling organisation.

4.2.1.6 Knowledge Valuation and Measurement

Within the context of knowledge management, valuation and measurement has traditionally related to the measurement of the success of knowledge management initiatives as well as the valuation of intellectual capital (Stewart, 1998). Although there is recognition of the value of intellectual capital, there is also a broader understanding of the financial and business objectives of both the technology providers as well as the end users:

"[Provider_3] are not so concerned about growth, they are concerned about profitability and having the right product to sustain their profitability in the long term. They're going to grow their company, but they are not going to sell that company. If they are going to sell the company on then it will be at the right time for them. It will not be driven by third party investors realizing, or doing an exit to realize the maximum value of the company." (Contact_1, Enabler_1)

More closely related to intellectual capital was an acknowledgement of the different methods used by the technology providers to leverage the value of their intellectual property:

"They are a small company but they are one company who have seen the [Enabler_1] model work from the point of view of generating enthusiasm to create a JIP proper, to create IP, whereas if you're talking about Provider_6, they have developed their own IP and have come to us to try and help find a field trial." (Contact_1, Enabler_1)

There can also be seen to be an implicit understanding of the value of the tacit procedural ('know how' type) knowledge within a technology provider, and the relationship between the value of this knowledge and the business objectives of that provider:

"They'll do it when they think the timing is right, and that could be five years, ten years, it could be two years down the line. It could be any time, but their mentality is to indigenously grow from their knowledge-base that they have retained in the company and solely to find things from their trading P & L, and from third party coming in through JIP-type projects. They'll neither borrow nor will they have a third party investor coming along with them, so in doing that we have to align ourselves in a very different mindset with any organization like that, because we can't drive them on the basis that they have unlimited cash and unlimited capability to deliver very substantial bits of project, without having to also track back to: "Right, where is the inherent fundamental support for this?"" (Contact_1, Enabler_1)

Contact_1 suggests that the value of the intellectual property of the technology providers is understood by both the technology providers themselves as well as the enabling organisation. However, he highlights the importance of acknowledging the roles of other types of knowledge in the innovation process such as managerial and financial (declarative) knowledge, which can also be seen to impact on the ability (and indeed the motivation) of the technology providers to take new technologies to the market. Contact_1 emphasises that there are differences in the ways in which the technology providers may wish to grow, and their associated needs to manage and protect their intellectual capital.

4.2.1.7 Summary of Key Enabler Organisation Findings

Process	**Findings**
Knowledge Acquisition and Learning	The enabling organisation acquires declarative knowledge reactively through its proposal process.
	The enabling organisation acquires knowledge during the commercialisation phase of projects through its relationships with both technology providers and end users.
	The management of personal relationships affects both what knowledge is acquired and how it is acquired by the enabling organisation.
Knowledge Transfer and Dissemination	The transfer and dissemination of knowledge between different players is reliant on the enabling organisation providing engagement opportunities.
	The acknowledgement of what knowledge not to share is recognised by the enabling organisation.
	The importance of identifying lead players within joint industry projects is recognised as a key factor for inter-organisational networking.
	Technology providers understand the importance of the role played by the enabling organisation in matching and transferring knowledge of technology needs.
	The enabling organisation acts as a knowledge conduit between the technology providers and end users.
Knowledge Storage and Maintenance	The proposal process forms the basis of a mechanism to store explicit declarative and procedural knowledge.
Knowledge Creation	The enabling organisation acts to facilitate and support the innovation process, but is not involved creatively.
Knowledge Application and Exploitation	The enabling organisation applies tacit and explicit declarative knowledge, knowledge of capabilities and knowledge of technologies.
	The enabling organisation aids the technology providers in their customer orientation through the application of tacit declarative, procedural and conditional knowledge.
	The enabling organisation also applies a new form of conditional knowledge: 'know where'
Knowledge Valuation and Measurement	The enabling organisation acknowledges the different methods used by the technology providers in leveraging the value of their IP.
	The enabling organisation implicitly understands the value of the tacit procedural knowledge of the technology providers
	The value of the IP of the technology providers is understood by both the providers and the enabling organisation.

Table 20: Key Enabler Organisation Findings

4.2.2 Technology Providers

This section provides the analysis of the knowledge-based processes and knowledge types and forms relating to the activities of the technology providers. Unlike the previous section which is based on the perspective of one organisation, this section is based on the narratives gleaned from six different technology providers.

4.2.2.1 Knowledge Acquisition and Learning

A number of the technology providers interviewed as part of the research start their stories with an identification and justification of the technical (procedural) and industrial (declarative) knowledge they had already acquired. In most instances, this knowledge has been gained either within academic contexts such as universities, through experience of working in different organisations within the industry, or more commonly a combination of both. The interviewee from Provider_1 for example implies his own procedural (‘know how’) knowledge through the academic context within which the technology was initially developed:

“We started this project at [University_6] around about the year 2000.” (Contact_9, Provider_1)

The interviewee from Provider_2 emphasises his own knowledge acquired through practical experience within the industry:

“My oilfield background is really fresh out of school, I started working offshore at the coal face as it were in 1982 for some of the major oil and gas service companies and then first got involved in an SME in 1995, a company called [Provider_22] which was just a two-man company.” (Contact_10, Provider_2)

In describing his background, another interviewee emphasises both the knowledge acquired in an academic context as well as the knowledge acquired through working within the industry:

“Well my background has been in design and engineering for a lot of years and I have worked for companies like [Provider_8], companies like [Provider_22] etc, so I have…and also my background, just after I left the University I went and worked offshore working with

some of the tools and equipment so I had a broad background in that sort of technology as has some of the other engineers here too." (Contact_14, Provider_6)

Clearly there is no standard path in relation to the acquisition of both procedural ('know how') as well as declarative industry-related knowledge for the technology providers. In relation to the specific technologies being provided by the organisations mentioned above, both Provider_1 and Provider_6 can be seen to be reliant on the declarative and procedural knowledge of the interviewees (both of whom are in key roles within their organisations). The reliance of Provider_2 on the procedural knowledge of this individual (as opposed to others within the organisation) in the development of innovative technologies is discussed later in this chapter.

Although the importance of the process of acquiring knowledge is evident within the technology providers, like the enabling organisation, the explicit nature of this process is not readily apparent. In relation to acquiring knowledge of funding and development opportunities, Contact_9 states:

"At that stage sort of mid-2000, we felt we had a great technology and were looking for ways of moving it forward. We found out about [Enabler_9]'s Proof of Concept Scheme - a fantastic scheme for academics. We spoke to [Enabler_9] and realized that it was ideal for this use and filled in a page of details of the technology and our plans - a kind of a questionnaire type of thing - and got through to the next round and filled in the next longer scale stuff." (Contact_9, Provider_1)

Similarly, Contact_14 from Provider_6 states:

"Being a young company at the time we were looking for routes to the market and you look at all avenues possible and [Enabler_1] were obviously an avenue that we should investigate. So quite early on we were put in touch with or we got in touch with…I'm not actually sure how it happened but we certainly started speaking to [Enabler_1] ... and since then we have been invited to put proposals in." (Contact_14, Provider_6)

Significantly then for the newer companies, both knowledge of funding opportunities to develop technologies ('know-what') and also the conditional knowledge of potential routes to market ('know when' and 'know where') can be seen to be critical success factors. Notably, the identification of a new form of conditional knowledge 'know where' is a significant finding for the research.

However, these in themselves can be seen to be insufficient. In addition, the procedural knowledge identified by Contact_9 (knowledge of how to engage with organisations providing potential funding opportunities) is essential.

Perhaps the best example of the importance of knowledge acquisition by the technology providers is given by Contact_10:

"I think being smart enough to know that you don't know everything about it and spending as much time in these presentations listening as you do talking, and sometimes that's something difficult to be disciplined about, is letting the industry and other people who are clearly quite knowledgeable, otherwise they wouldn't be doing some of the jobs they are doing, give you some feedback. In fact an example of that with our particular system, was somebody else said to us that our wells will simplify the abandonment process because we won't have all the overlapping casings of surface that a potential leak paths back to the seabed because we might only have one or two overlapping casings at the top of our wells, and consequently the abandonment process is simplified. But if we hadn't have gone and done that presentation we would never have realized that, and for all we know that could end up being the most significant selling benefit to our system in the North Sea where the cost of abandonment is going to be a huge issue." (Contact_10, Provider_2)

Not only does Contact_10 emphasise the importance of the engagement of the potential end users of the technologies within the innovation process in relation to guiding the development of the technologies, but also highlights the need for absorptive capacity in the technology developers themselves. As suggested by the interviewee, the end users themselves are important sources of knowledge specifically in relation to potential areas of application of new technologies, and also the benefits of those technologies which may differ from the benefits identified by the technology providers.

Specifically in relation to Enabler_1, one interviewee highlights the importance of the role to technology providers which this organisation plays:

"*So…You are obviously aware of what [Enabler_1] do, but at the time it was explained to me that they were championed by the oil operators to look for innovative technologies."* (Contact_13, Provider_5)

Contact_13 presents a view of the enabling organisation as proactively seeking out new technologies for their member companies. Although this supports the enabling organisation's own view of their practice, it does however not readily fit with the reactive process used by Enabler_1 to acquire knowledge of innovative technologies. This would seem to imply and subsequently support the relatively informal role of Contact_1 in acquiring 'know what' and 'know how' knowledge types though networking.

4.2.2.2 Knowledge Transfer and Dissemination

In relation to the process of transferring knowledge, the technology providers have a good appreciation of both the importance of transferring knowledge (particularly 'know what' knowledge of their own technologies), as well as the different roles played by the actors in the knowledge transfer process. The technology providers can be seen to transfer knowledge to the (potential) end users themselves directly using traditional marketing techniques, as well as indirectly using an enabling organisation.

Generally, the providers recognise that it is not only through their engagement with the enabling organisation that potential end users become aware both of the providers themselves ('know who'), but also their capabilities ('know how') and their technologies ('know what'). Provider_2 acknowledges that it is through the active marketing both of the organisation and its technologies that potential end users may initially identify potential providers of technologies which may be applicable to them:

"And a lot of the innovation process in terms of people becoming aware of the technology comes in the marketing of it, the way that the business itself is profiled and the structure you choose to, the vehicles you choose to try and commercialize the technology." (Contact_10, Provider_2)

Similarly Provider_5 identifies the importance of using industry events to transfer declarative knowledge:

"*I was at a conference about 2 years ago and I was doing a paper promoting the technology and a [End User_1] guy followed me who works in the [Area_1]. He was really keen on this because he knew [End User_1] was one of our sponsors. We discussed it over dinner and he said: "Right, I think we can get a case for this."”'* (Contact_13, Provider_5)

The providers also recognise the critical role played by Enabler_1 in acting as a facilitator to the process of transferring declarative (‘know what’) type knowledge. As mentioned above, Enabler_1 can be seen to fulfil the classic functions of an enabling organisation by acting as a source and conduit of information and knowledge, and as an integrator (Azzone and Maccarone, 1997). By arranging opportunities for technology providers to present their technologies to potential end users, Enabler_1 in effect allows for the direct transfer of knowledge between these two groups. However, this is dependent both on Enabler_1’s own understanding of the technologies and capabilities of the technology providers (‘know what’ and ‘know how’ knowledge types) as well as the requirements of the end users in relation to the technologies themselves (‘know what’), and their potential areas of application (‘know where’ and ‘know when’ knowledge):

“So basically we were invited to present a 30-minute presentation on that particular product which was a down hole equalizing device which we had designed and [Enabler_1] had invited members of that group of companies that might be interested in running that with a view to try and get people to commit to giving a candidate well that the product could be run into or basically try and encourage companies to use it. And they also as part of that process as well would be that they would go out and try and encourage people to use this product.” (Contact_14, Provider_6)

Enabler_1’s absorptive capacity is evidently a critical element in the ability of the technology providers to transfer knowledge to their potential end users. The proactivity of Enabler_1 in their engagement with end users can also be seen to be not restricted by the funding process itself:

“[Enabler_1] set the wheels in motion and they were very helpful in so far that they made an approach to the potential sponsors notwithstanding the fact that we had been there not for sponsorship. We were there to say “Look, here is an idea. We want to develop this idea, and we think this idea would be good technology and help you guys add value. It’s good for the environment, good for removing structures, and focused on decommissioning.”” (Contact_13, Provider_5)

Once again, the process of knowledge transfer can be seen to be dependent on a number of factors which may act as catalysts or inhibitors (Davenport and Prusak, 2000). Provider_5 suggests that one factor affecting this process is the relationships which exist between the enabler and the end users:

"[Enabler_1]'s role was from our point of view very good and simplistic. Obviously there was a lot of work on in [Enabler_1] that we don't know, but as far as we were concerned we were an SME and we didn't have enough funding to exploit this thing. They took it on board, they went and sweet-talked the oil companies and managed to get us funding from four, and for that we are very grateful." (Contact_13, Provider_5)

While supporting the importance of networking in the transfer of knowledge (Swan et al, 1999), Contact_9 also highlights the difficulties in securing funding within groups containing representatives from different organisations which may also have different technology priorities:

"We met up with [End User_4] pretty soon after that and they suggested meeting with a number of different operators. They in turn suggested meeting with a number of other people so by the end of the summer of that year we had a Joint Industry Project with the idea of taking it from where it was with this Proof of Concept, and we had a video of this leaking seal and taking that and looking at a range of leakage situations. To do that it was an extremely hard process of moving through." (Contact_9, Provider_1)

However for one organisation which has not engaged in a joint industry project, the importance of individual contacts can be seen to be critical. Indeed, the interviewee seems to imply that the contacts themselves and the engagement with them are almost more important than the innovative nature of the technology itself:

"*So we've got success. We've got stuff on the ground here, we've got stuff in the [Area_3] and [Area_4] and now we've got some orders for people in [Area_1]. So the name is getting out there, and that's purely me having existing contacts and getting work, and that's me doing some work that I think is not hugely innovative but is a solution for some things. But none of them are things that I would value to patent or to think of anything for it's just a quick turnaround thing. That's what a lot of the smaller companies around here do."* (Contact_11, Provider_3)

Linked to the importance of both formal and informal networking can be seen to be the use of marketing to promote the technologies, and as a formalised vehicle for knowledge transfer:

"*We have to say it's not the answer to every scenario. It will go through mud and even soft soil and soft grout, all remote-operated by computer. It's quite an exciting project for us* *taking it from a dream to reality. It took a while - a couple of years or so. But the problem we have or have had is marketing, in that who wants to be the first to use it? The project engineer is probably thinking: "Does it work?""* (Contact_13, Provider_5)

Contact_13 thus identifies an additional type of procedural knowledge important to the technology providers: marketing knowledge. Contact_12 also emphasises the importance and difficulty of marketing new technologies, however the interview goes on to acknowledge the role of the enabling organisation in customer relationship management which thus allows Provider_4 to focus on the development of the technologies, rather than what may appear to be more peripheral activities such as marketing:

"It was based more on knowing people, at the time there was a guy I knew relatively well who is gone now. He was in [Provider_24] and then he moved onto [Enabler_1] for a period of several years and it was in discussions with him and he knows we are fairly innovative. We keep coming up with ideas and he kept saying: "Do you guys have any ideas?" I have in the past tried selling JIPs. In the past we have done a number of JIPs. The killer in a JIP is not the work but the killer is you sometimes spend more effort on the sales side and trying to massage the customers and make the whole thing flow than you do on actually doing the work. So I had almost sworn off JIPs to the point that I said: "This is ridiculous." It was such a hassle. Then [Enabler_1] said: "Well that's our job. Let us do the legwork for you. You just come up with the ideas." So [Project_2] was the one we tried." (Contact_12, Provider_4)

Contact_11 acknowledges both the previous perspectives of other technology providers, and also the role of the enabling organisation in the formal promotion of the technologies to their member organisations. The interviewee suggests that both a formal and informal approach to promoting a technology are necessary for innovative technologies to be applied by end users, and that the enabling organisation alone is not sufficient to ensure the uptake of the technologies by those organisations:

"So you get a lot of visibility by doing it through the [Enabler_1], but you have to push it yourself hard as well because even though it goes to a guy in [End User_4] or something who then distributes it to a few people within [End User_4] globally, quite often it doesn't land on the right person's desk. If your contact is in [End User_4] or [End User_6] or [End User_1] or whoever, it may be you can quite often push it through, but you need to be on top of it. So if you don't know the customers, if you were purely an R&D group that didn't have any exposure to outside customers, it would be very hard to get the technology accepted. But once you have a successful JIP completed, it does get distributed to people over the world within

the operators, so you do get a lot of publicity out of it which is good. But you do have to be on top of it. It's not something you can just drop." (Contact_11, Provider_3)

Like Contact_1, Contact_11 emphasises the importance of the relationships as a potential influencing factor in the development of new technologies. Not only is there a need for an understanding of the potential beneficiaries of a technology, but also for the technology providers to proactively market the technologies, rather than leaving that role solely to an enabling organisation, or serendipity.

4.2.2.3 Knowledge Storage and Maintenance

The storage and maintenance of knowledge by the technology providers is not explicitly identifiable as a knowledge-based activity within the innovation process. Although the technology providers appear to participate in Enabler_1's project proposal procedure (which is itself a process of acquisition and storage of explicit knowledge by Enabler_1), there is no mention made of what explicit knowledge is stored by the technology providers by and for themselves.

As can be seen above, much of the knowledge of the technology providers is largely tacit in terms of their declarative and procedural knowledge ('know what' and 'know how'), the players within the industry ('know who') and the areas of application of their technologies ('know where' and 'know when'). However one interviewee does acknowledge the importance of providing documented explicit knowledge in the form of reports for both Enabler_1 and an additional funding body:

"Anyway what happened was I knew [Contact_2] at [Enabler_1]. We spoke to them and we had a launch meeting on the 22nd August. It showed the four sponsors were interested, so basically we had a whole bunch of stuff to fill out for [Enabler_1]. We also had letters from [End User_1] way back saying that whilst they were not planning at that point to decommission in the short term, they were saying that they were very interested in what we were doing, and we had a similar one from [End User_4]. Now when you consider it was just on the drawing board at that time…We did as part of the deal for [Award_4], we had to do a little bit of paperwork: how we were marketing it, where we were going, etc and give them all reports, and also the other various cutting options available and the advantages, disadvantages of this and where it fitted in." (Contact_13, Provider_5)

However this example provided by Contact_13 can be seen to show that the demand for this documented knowledge follows a period of personal interaction with both the enabling organisation and the end users themselves. The interviewee suggests then that it was the opportunity to share knowledge face-to-face that triggered the need for more explicit documented knowledge.

4.2.2.4 Knowledge Creation

Following on from the rather cursory identification of the storage of explicit knowledge by the technology providers, they reflect on the initial creation of knowledge which subsequently led to the development of a technological innovation. This point can be seen to be clearly indicated by the following quote from Contact_9:

"We really quickly after that realized that the devices which we call platelets were more than just leak sealers, that they could actually detect leaks as well by identifying a tag inside them so you're losing the actual need to use this pipeline pig in the first instance. That identification tag could be a radioisotope or it could be radio frequency, or there's a whole realm of different tagging techniques that you could use." (Contact_9, Provider_1)

Although the interviewee from Provider_1 can be seen to participate in the initial 'Eureka' moment, other providers appear to place less emphasis on this highly important stage within the innovation process. Underpinning the knowledge creation process however, Provider_1 emphasises the relationship between the ability to develop an idea or create a new technology and knowledge in the form of expertise:

"Our backgrounds are in fluid mechanics, so it's understanding how things move in the fluid. So it's part of our expertise." (Contact_9, Provider_1)

Similarly the interviewee from Provider_2 understates the role of knowledge creation within the innovation process by suggesting its relative simplicity in relation to the process of commercialisation:

"The development of the technology, there is a practical set of solutions and then the strategies that are required to commercialize that technology, and we find the commercialization is actually more difficult than the development." (Contact_10, Provider_2)

Provider_ 4 for example highlights the perspective placed on more incremental forms of innovation, which in this instance is seen as somehow less innovative due to its (from the interviewee's perspective) relative obviousness:

"And so now we have a product and of course there is always more work to do and we are now in phase two so it's not a great example of innovation in the sense that the idea was pretty obvious but the challenge was getting it to fruition." (Contact_12, Provider_4)

An issue which perhaps the interviewee from Provider_4 does not acknowledge is that although this novel technology may not be seen as particularly innovative by him or his organisation, it is his own declarative and procedural knowledge ('know what' and 'know how') that has given him this perspective, and that others who do not possess this knowledge may view it as highly innovative. Additionally, Provider_4 supports the perspective presented by Rothwell (1994) in his view of early innovation models, where the market was a receptacle of research and development, even in a case of incremental innovation such as this.

Once again, the importance of personal interaction can be seen to be critical. The interviewee from Provider_2 highlights the value of gaining the perspectives of others both inside and outside the organisation in order to both acquire new knowledge which may influence the development of the technology itself, as well as helping to determine the value of that technology:

"So it's not necessarily the person who is knowledgeable in the area of drilling wells that conceives these things, it can often be someone who is coming from a completely different perspective and says "Well why don't you do this?" Of course that's the measure of inventiveness; you know a good idea is often obvious after somebody has told you it, but that's what determines inventive step. If it wasn't obvious until somebody suggested it to you, then that's an invention." (Contact_10, Provider_2)

As has already been mentioned, the enabling organisation as well as a number of the technology providers can be seen to recognise that they are being taken away from what they consider to be their key role in developing new technologies in order to manage less core (yet equally important) activities within the innovation process, such as sales and marketing. The importance of declarative ('know who') knowledge to the technology providers is apparent. This not only relates to potential end users of the technologies but, as can be seen above, the organisations acting to enable the process as a whole.

4.2.2.5 Knowledge Application and Exploitation

The application and exploitation of knowledge by the technology providers can be seen to be a critical element within the process of developing new technologies, and one which the interviewees had clearly reflected upon. Additionally, it can also be seen to be closely linked and indeed stimulated by knowledge creation (Nonaka and Takeuchi, 1995). This link between the knowledge creation process and the subsequent application of that knowledge is neatly emphasised by the interviewee from Provider_2 who states:

"I think that really the interesting part of the innovative process is the practical set of solutions, because that is where the detailed ideas get turned into reality, and the clever little bells and whistles you put on the technology to make it work. It is an interesting journey." (Contact_10, Provider_2)

The interviewee also acknowledges the ongoing nature of the innovation process which does not end with the development, commercialisation and application of one technology, but very often leads to the incremental development of a series of technologies:

"I think what we can envisage is that our system will evolve and be able to do more and more. We can conceive that the [Project_1] system which is currently a well construction method where the well is already drilled, the hole is already drilled and we've got a method for installing the casings. We think that we can evolve this to be a situation where we use the [Project_1] technique to drill the well and insert the casing at the same time. But we've got to get through generation one before we can perhaps move onto generation two, and I also think that that some of our innovations and some of our technologies will be complimentary to other things right now that appear to be competitive." (Contact_10, Provider_2)

Provider_2 thus emphasises the importance of the contexts within which the development of new technologies happen. Within the context of the interviewee's own organisation, there can be seen to be an awareness of the need for the transfer of knowledge between individuals and teams in order to create a new technology:

"…there's a design-engineering element to this where you've got the basic fundamental things that you want to do and you've got to apply the detailed design engineering and consequently you need a design engineering team. But they actually can't work in isolation, they need to be fed with the basic concepts of what you are trying to achieve and the

basic…the fundamentals of it can't be any bigger than this, it can't be any smaller than this and it needs to be made with this kind of materials. And then of course then clever design engineers can then turn that into a set of workable solutions and tools so that's actually a very important part of the process and that is often the part that many, many companies can do." (Contact_10, Provider_2)

The interviewee thus makes links between not only the creation and subsequent application of knowledge, but also emphasises the importance of the transfer of declarative knowledge within the innovation process. The importance of knowledge transfer (specifically through the use of brainstorming sessions) in identifying technological gaps for the operators which the technology providers could subsequently fill though the application of their knowledge is also apparent from the following quote:

"I had a broad background in that sort of technology as has some of the other engineers here too. So before we started the company up we obviously brainstormed what products were missing and would be useful for operators to have as part of their tool kit that would allow them to do workovers and completions and similar type of operations." (Contact_14, Provider_6)

The importance of applying the declarative ('know what') knowledge of the team involved in all elements of the innovation process, and the importance of the different perspectives that this knowledge provides is also identified by Contact_10:

"It was quite interesting bringing that team together as well, and I think a lot of people think that the way that new technology comes into the oil field. It's all about men going around in white coats in labs assembling and tinkering with things, and eventually this product is finished and all you need to do is roll it out of the warehouse and everyone starts buying it, and it starts going in wells. It's much, much more complex than that. So the other thing is trying to get a team of people together who aren't all clones of each other as well. So you've got the different disciplines and people who have different perspectives on all the different disciplines, and you end up with this what needs to be a cohesive team to be able to deliver the product." (Contact_10, Provider_2)

Perhaps somewhat ironically considering the importance of the application of knowledge within the innovation process it can be seen from the interviews with a number of the technology providers that the actual process of development, building and testing is addressed in a rather matter-of-fact way, which underplays the inherent complexities associated with the development of any new technology:

“After we’d developed it and did all the engineering and built the prototype, we then had to test it and that’s where [Enabler_1] came in.” (Contact_13, Provider_5)

This perspective is also echoed in the following quote from Contact_12 who, while acknowledging the scope of work required to develop the technology, appears to have less of a concern with the application of the knowledge of Provider_4 in turning a concept into a product, but more with the subsequent application of the technology by the end users themselves:

“There was a fair amount of work needed to be done. We had to build [Project_2]’s big dust machines and we had to do testing and of course there is always the question of: “if we had it, would customers use it?”” (Contact_12, Provider_4)

This issue is further elaborated upon by the interviewee, who clearly identifies it as a critical issue:

“So you have two things. Do you want to take the technical risk? There is no technical risk, I mean you knew you could do this, there was no question it could be done so there really wasn’t a technical risk but there was a significant market risk.” (Contact_12, Provider_4)

Importantly, the interviewee acknowledges that one key issue in the innovation process in relation to this specific technology is not in the technical development of the technology itself (as the interviewee clearly identifies that the organisation had the ‘know how’ required), but in its subsequent uptake by the end users. The interviewee also acknowledges some of the difficulties in getting new technologies adopted by end users within the context of the global oil and gas industry:

“The fact is that everyone is so busy that our business has almost doubled in the last 2 years. So everybody is so busy and it’s hard to find time to do something that you’ve never had to do before. [Project_2] comes under that category of things that we’ve never done in the past, so why should we do it now? And yet there is a host of reasons why they should do it. The operators are interested in seeing this done and the service companies are saying: “OK, you’ve got to pay us more to do this.” Of course the answer to that is no.” (Contact_12, Provider_4)

The difficulty in getting new technologies to market is further emphasised by another interviewee who also implicitly acknowledges the importance of conditional knowledge in the form of knowing when to introduce new technologies, and also more generally knowledge of the market for new technologies:

"Within the oil and gas industry and it's because of the cycles that we go through, I think over the decades, less and less people are involved in the oil and gas industry because every time there is a downturn we lose a few and then there's an upturn and not as many come back in. So consequently over time you've got less and less people trying to do more and more and of course as soon as activity levels go up people are too busy. We've got a situation where there is low activity and people say: "Come back and talk to me about that when I'm busier because I'm not doing anything at the moment." Then suddenly there's an uplift in activity and they say: "I've no time to look at that just now because I'm too busy." Technology has to be introduced at just the right window because you won't get anybody to use anything new when there is no activity because they don't have the funds available to be able to support it. You'll struggle to get people to have the time to take an interest in it when activity levels are very, very high, so the window of opportunity is only open for so long. If you bring your technology into the marketplace at just the right time so that you've got that full window open, that's great because you're still involved in the activity levels when your system is ready." (Contact_10, Provider_2)

Knowledge of the contexts within which these technologies may be applied is evident from a number of the interviews with the technology providers. Contact_14 for example, highlights the benefits of developing technologies for an area noted for its difficult operating environment:

"All the products that we are developing here are aimed at the global market; it's not really just [Area_11] although obviously for a small company you focus at the markets close to you. But the good thing about the [Area_11] is that if you develop a product for there it's very transferable, it's kind of all over the place. You've really got to be global now; you can't really rely on [Area_11] as a place to make your fortune anymore really. You need to look further afield." (Contact_14, Provider_6)

Similarly, Contact_13 identifies why it is so important to have a good understanding of, not only the economic, but also the physical environments within which the technologies may be applied:

"It's interesting as well from the market research we've done before. We felt that there was a big market for it in [Area_18] and maybe later in [Area_11]. We've now moved that a little bit. We now think not necessarily because of the hurricanes but because of the structures that are in [Area_1], that there may be a stronger case for more opportunities in [Area_1], and in other parts of the world. But in other parts of the world they can't afford to take them out." (Contact_13, Provider_5)

Similarly, Contact_12 identifies markets where the Provider_4 technologies are not applicable for socio-economic reasons:

"We started fatigue in 1988 and now coil-tubing fatigue is very common and almost everyone uses it, but there was a gradual transition throughout those years. There are a few places out there that don't bother. [Area_9] for example doesn't use fatigue calculations. They run it until it breaks. So there are still places that don't bother, so it will probably never be that everyone in the world is using [Project_2] fatigue calculations." (Contact_12, Provider_4)

In relation to the broader issue of the economic climate of the global oil and gas industry, one of the difficulties for the technology providers can be seen to be that they are forced into a more reactive mode of interaction with the end users:

"To be frank it's a fairly low priority project for us. It gets a burst of energy every once in a while. We don't do anything with it and then it gets another burst. Right now we are in the middle of a burst of energy. It's been likewise on the customer side. You know, they ignore us for a period of time and then all of a sudden they start asking questions." (Contact_12, Provider_4)

However, during periods of high activity for the end users, their input to the technology providers in the form of identifying opportunities through conditional knowledge ('know where' and 'know when') for the application of the technologies can be seen to be of high value to the providers, such as Provider_3:

"…we provide them with regular updates on the progress we're making. We did have to go back to them once to change some parameters slightly, and that was fine so there was no real involvement from them technically. What they are putting in is they are looking for applications to use the technology in, which for us is far more important. It works well because they leave us alone. They trust us and they leave us alone to get on with the

development. We supply regular updates so they know what's going on, and at the same time they are looking for places to use it which is far more important for us because we get it out there and we get it tested in the ground. In that, I think actually [End User_4] has probably been the most active because they have already identified a number of opportunities where they want to use the technology. So that's good, and we're now speaking to them already even though it's not completed yet." (Contact_11, Provider_3)

Contact_11 also emphasises the importance of other knowledge-based processes in relation to knowledge creation by acknowledging the importance of trust (noted by Davenport and Prusak (2000) as a key barrier to knowledge transfer) and the need to share knowledge with the end users to identify how the process is progressing and, as stated above, where the technologies may be applied.

4.2.2.6 Knowledge Valuation and Measurement

Similar to the perspective presented by the representative from the enabling organisation, several of the technology providers appear to have a clear understanding of the value of their intellectual property, the importance of protecting their intellectual property, as well as the broader economic environment within which they are operating. Naturally within this environment the technology providers can be seen to have a good understanding of the impact of fluctuations of the price of oil have on their ability to develop new technologies, and to have those technologies applied by potential end users:

"When you look at high oil prices stimulating activity, it means there's more money swilling around to be able to invest in new ideas that can become the next generation of wells. But I think it's also got the potential to stifle technology because people find it makes much more economic sense because we know what the fixed cost basis of doing the well is now, and it was economic at $10/$12/$13 a barrel. It's clearly more economic at $60/$70 a barrel so it's got the potential to stifle development as well because overwhelmingly it's a commercial success based on using old technology, and keeping it simple and using things that are well known and well understood even if they aren't the most efficient and most effective ways, it's almost outweighed by the commercial upside." (Contact_10, Provider_2)

Contact_10 suggests that it is not necessarily a high oil price which stimulates the demand for innovative technologies by the end users. On the contrary, the interviewee suggests that the end users are less inclined to use new technologies when the oil price is high due to the financial rewards of using existing technologies. Within this context, the technology providers then cannot be reliant on funding from the end users to develop new technologies. Instead, a number of the providers can be seen to fund the development of the technologies themselves with the expectation that the end users will acknowledge the benefits (both economic and technical) of applying the technologies:

"It had sat dormant for probably two years. Nothing had happened with it for two years for lack of somebody with, dare I say the balls to commercialise it and raise the funds required. We've spent two million pounds on [Project_1] over the last 18 months, so there was nobody else out there prepared to invest those kind of sums to turn it into a reality. There's a significant journey of investment still to go so the [Enabler_1] connection there, for us has been extremely valuable. I can't say that any pound, shilling and pence have come from [Enabler_1] directly or even from any of the operators directly, but what it did do it got us in front of the right audience to allow us to present what [Project_1] was and actually create a lot of interest in the potential benefits of technology in the operating community."
(Contact_10, Provider_2)

Contact_10 also acknowledges the importance of having declarative knowledge of both the perceived needs of the end users, as well as the different factors which may drive the application of a new technology within the end user organisations. In relation to knowledge valuation, the interviewee suggests that in effect different end users may place a different value on the application of the technology due to their own internal priorities:

"It's a continuous innovation process because you'll go up the road of the people saying: "Well, no that's not the one I want." and that could be because you sold it to them incorrectly. And you could go to the next group with exactly the same thing and with a different set of pros and cons and sell them what the upside that they are looking for with exactly the same system you can make it a commercial reality. But if you're hell-bent on telling them it just gives you a bigger size of pipe across the reservoir then well I'm just not interested in that. We've had people within [End User_1] in certain parts of the world that have said: "All other technical things being equal, if you can truly reduce the magnitude of the cuttings that are produced from an environmental point of view…That's my biggest problem in this particular part of the world, having to take all the cuttings and clean them and dispose of them in a land-fill site, and all the other things are that big an issue for us." Well of course if you hadn't emphasized the environmental benefits to that particular group you might not have sold the technology to them, whereas in other parts of the world the cuttings disposal is not a big issue at all. Maybe for example in the [Area_11] a lot of

emphasis is placed on safety so our system means less and less pipe logistically has to go to the well site and much smaller diameter pipes are used right from the outset, so there's a significant reduction in risk from a safety point of view and that might be actually be one of the things that clinch it for areas of the [Area_11]. Other parts of the world it is a combination of these things, but other places a bigger size of pipe that allows you to put a bigger set of perforating guns in which gives you bigger holes in the casing and bigger penetration into the rock and consequently give you more production…If you didn't emphasize that to a particular group you might not sell it to them either." (Contact_10, Provider_2)

Provider_5 also acknowledges how the vagaries of the market can affect the funding of technologies by end users:

"So [End User_1], [End User_4], [End User_6] and [End User_8] all gave us £80,000 each to carry out the function trials. [End User_10] were very interested and wanted to sponsor us as well, there was no commitment by us. They just wanted to enhance the technology. No strings attached. Unfortunately at the time [End User_10] were going through a cessation program, and there were lots of bids out and they couldn't even give us one kroner because during a bid process they are not allowed to be seen to be enhancing anybody's technology, which I can understand. So we got four sponsors." (Contact_13, Provider_5)

The importance of protecting the intellectual property of the technology providers through patenting was also made apparent by this interviewee:

"The technology is patented as well. I always do this because particularly in [Area_18] they tend to try and circumvent anything simple. You'll get a guy in a workshop, just say a diving company or a sub sea contractor, and he's maybe seen the diamond wire in action. He hasn't got a clue, and doesn't think about patents and he goes to his project manager and says: "I've made one of these machines for you." But there are two patents: the methods and the two or more pulleys in water, so they're quite strong patents we've got." (Contact_13, Provider_5)

This was clearly a significant issue for Provider_5, as the organisation had developed the technology itself, and is naturally keen to ensure that it was not misappropriated. However Provider_2 (as was acknowledged by the enabling organisation in section 4.2.1) does not develop its own technologies, and instead acquires the intellectual property from a third party.

In relation to the development of a new technology, this can clearly be seen to be critical for this organisation, and stimulates the development of a number of new technologies:

"We were able to locate and acquire some patents that had been applied for in the late 90's, and these patents were about the concept of constructing [Project_1] wells. So having secured that intellectual property we went about creating the practical set of solutions which often is where much of the innovation actually is which leads to commercialization because there are a lot of clever ideas and inventions out there that created but they sit on the shelf for lack of commercial creation. We assembled a team of people around this technology and specifically to allow [Provider_2] to become the commercialization vehicle of the technology. So having acquired initially some pre-existing concept patents we went about making the inventions of [Project_1] and actually applying for a considerable number of new patent applications." (Contact_10, Provider_2)

In many of the development projects which can be seen to be funded by joint industry projects with groups of end users brought together by the enabling organisation, exclusivity rights are commonplace with end users demanding the exclusive use of the technology for a given period before it is made available to the rest of the market. However, this is not always the case. Unlike Provider_2 and Provider_5, Provider_4 acknowledges that both for the technology providers and the end users in a number of instances, it is more important for the technology to be used initially than for it to be rigorously protected which may in fact hinder its application:

"There is no exclusivity. They have no interest in exclusivity. They just want the technology. In fact it looks like the first customer that will end up using it will be in [Area_3]. The company that seems most interested is called [End User_16] in [Area_3] and of course [End User_4] and [End User_1] have never heard of them, but our attitude is if anyone out there is willing to use it, let's get it out and get it used and get experience with it." (Contact_12, Provider_4)

Although the technology providers themselves have clearly established needs to protect their intellectual property, the end users' (as can be seen from the above quote) views on this issues seem to vary. While the exclusive use of technologies may be seen as paramount to some organisations, others appear to be more interested in their own use of the technology, rather than detracting from its use by other end users.

4.2.2.7 Summary of Key Technology Provider Findings

Process	Findings
Knowledge Acquisition and Learning	The technology providers acquire both procedural and declarative knowledge from academic contexts and industry experience.
	Acquiring declarative knowledge of funding opportunities and conditional knowledge of routes to market is critical to technology providers.
	The end users act as a source of conditional knowledge for the technology providers.
	The technology providers require sufficient absorptive capacity to acquire knowledge from the end users.
	End users recognise the role played by the enabling organisations in acquiring declarative and procedural knowledge.
Knowledge Transfer and Dissemination	Technology providers recognise the importance of transferring knowledge, and the roles of the actors themselves.
	Technology providers transfer declarative and procedural knowledge directly to the end users and indirectly via the enabling organisation.
	The enabling organisation is seen as a critical facilitator of declarative knowledge transfer.
	The relationships which exist between the enabler and the end users affect the knowledge transfer process.
	Marketing technologies provides a formalised vehicle for knowledge transfer.
Knowledge Storage and Maintenance	Declarative, procedural, and conditional knowledge are stored by the technology providers in tacit form.
Knowledge Creation	Knowledge creation is poorly recognised by the technology providers as a critical element of the innovation process.
	Expertise is seen as essential to the technological innovation process.
	The enabling organisation acts as a support function to the technology providers thus allowing them to focus on the development of new technologies.
Knowledge Application and Exploitation	Application of knowledge by the technology providers is critical to the development of new technologies.
	Knowledge transfer helps to identify technology gaps which the providers may fill through the application of their knowledge.
	Contextual knowledge of the environments within which technologies may be applied is seen as highly important.
Knowledge Valuation and Measurement	The technology providers have a good understanding of the value of their IP, the importance of protecting it, and the economic context.

Table 21: Key Technology Provider Findings

4.2.3 End User Organisations

4.2.3.1 Knowledge Acquisition and Learning

Although the geographical environment of the UK upstream oil and gas industry can be seen to be relatively constant, all of the end user organisations who participated in the study also operate in other locations which have different environments, and consequently have different technological needs to accommodate those environments. However, one end user does note the value of the enabling organisation as a vehicle for the acquisition of declarative knowledge of new technologies ('know what') specifically in relation to a more localised context:

"On a more local basis, certainly with [Area_11], we have funding that supports [Enabler_1], because [Enabler_1] is seen as a means of collating information in the sense of the workshops that they run earlier in the year, which we find to be extremely valuable because they give us a chance to sit in on those workshops and input what we feel are the technology needs or gaps, or where the problems are. We are also sitting in on the workshops with operators and other major service companies that are obviously putting in their requirements." (Contact_3, End User_1)

Similarly, Contact_7 acknowledges the role of the enabling organisation as a facilitator of knowledge acquisition within a specific subject domain, but limited to a localised context. Again, the importance of finding technologies which fit the modus operandi of the end user organisation is apparent:

"At the time I was working with technology at [End User_5]. I was in the wells group as the business performance engineer, so I was responsible for the wells new technology, introducing new technology, increasing awareness, things like that, so I was involved with the [Enabler_1] for that reason. So the wells group in [End User_5] is pretty active. It's pretty big, so what I did was look at all the [Enabler_1] technologies and then I would screen them, the wells ones, I'm not talking about others outside the wells group. I wasn't looking at those. What I would do is screen them, and I think I picked out five or seven that I thought would be directly applicable to the wells, to [End User_5] as a company, but implemented through the wells group. Technology that I thought would fit our mode of operation, and what I did was try to promote those and push those along at least to the point to find out if they were worthwhile. Of those a few of them had promise. A few of them were looked at internally

within the wells group in that I got somebody in the wells group to have enough interest to look into it further." (Contact_7, End User_5)

However, the interviewee does also acknowledge that the areas of technological focus within the organisation were prone to change, and as such may affect which technologies are adopted, and indeed the point at which they may be adopted by the end users. This issue can be seen to relate to the importance of the enabling organisation regularly acquiring knowledge relating to the technology needs of the end users, and transferring that declarative knowledge on to the technology providers.

"So that's what I had done – [Enabler_1] had introduced it and a number of other technologies, and I screened it down to a certain number and one of those caught fire and took off. And some of the others that we got from [Enabler_1] did also carry on. One was [Project_8], which we did some internal studying with, and so on. But what happened with that one is we got interested into looking at vibration issues and drilling and we realize: "Oh wait a minute; we're not handling vibration enough in a lot of other ways. Never mind what a tool can do for us." At the same time we were having vibration issues on another tool, and they kind of came together and said: "Hold on, before we try a tool let's understand vibration more". So we got sort of sidetracked and we didn't get back to [Project_8], but we may well have since." (Contact_7, End User_5)

Another interviewee noted a more formalised approach to the identification of potentially beneficial technologies, as well as conditional knowledge in the form of the identification of areas in which the technology could be of benefit:

"*So that's where we sit as a rule now. We tend to have what are known as technology themes, so we have what you might call a vision which looks at what we need across [End User_1] worldwide, and certainly within [Area_11] locally, so there's two pieces to it. That is, what are the technologies? Where are the things that we have problems? So what technologies do we need to see develop in the industry in order to deliver solutions for what we can see? So on a global basis, one of them could be for example sand control because we've more and more of our wells becoming wells that have a sand production problem, so we need to have the technologies that one, can actually prevent the sand coming into the well wall in the first place, and secondly if the sand comes in, what are the remedial options that we can do?***"**
(Contact_3, End User_1)

With specific reference to the identification of new technologies, this more formalised and structured approach appears to have a potential impact on the technology providers if the technologies offered by the providers do not fit within an existing theme. However, as the themes in End User_1 (as with most of the other end users within the sample) are determined globally, the potential uptake from the providers (such as Provider_3 below) is significant:

"So when we saw the submissions that came in from the [Enabler_1] in June, July time saying, these are things that are in answer to the request made earlier in the year, the metal-to-metal seal that [Provider_3] came up with caught our interest because we'd identified integrity as an issue that we needed to work more on, and we were looking for other solutions, and their technology of having a metal-to-metal seal which could either be possibly retro-fitted into Christmas tree tubing hanging areas and therefore possibly get rid of the elastometric seals there, but also the fact that we could get metal-to-metal seals on the plugs." (Contact_3, End User_1)

The need for Enabler_1 to have a good understanding of both the technical themes and business drivers of the end users is essential therefore to the innovation process if the technologies being developed by the providers are to be taken up by the end users using Enabler_1 as a facilitator of that process. However as noted by Contact_4, one of the difficulties facing Enabler_1 is in reconciling the different priorities of its member companies:

"Again, if the opportunity is there you can make use of it, one of the hard things for [Enabler_1] is for them to bring that innovations to you but they don't know our business case so they don't know the drivers or know what our current desires are and they change on a day-to-day basis. So it's quite a hard thing to do a good job as best they can and we don't all have the same drivers…The [End User_4] guys will take eighteen months to plan a well. We'll take ten weeks." (Contact_4, End User_2)

The need to understand the technological needs of the end users can be seen to be critical not only for Enabler_1, but also other end users. As many end users within the upstream oil and gas industry are part of a larger group of organisations, it is the priorities of a number of groups which can influence the technological themes decided upon, and consequently which technologies are adopted:

"We visit our sister companies and ask: "What are your needs?" For example, if you need to drill in 2km of water you need technology for that, or if you have a problem with the seismic imaging you need to approach the geophysics community. So, we put all of this together and

we make a ranking to decide which ones are more important, and we allocate the budget and make a plan. Another contribution to this process comes from [Enabler_1]. We try to take advantage from our membership with [Enabler_1] because we consider [Enabler_1] one of the most effective generators of opportunities for technological innovation." (Contact_5, End User_3)

The acquisition of knowledge from other industry sectors (technology transfer) is also apparent within the end user organisations. Once again, the role of serendipitous knowledge acquisition is apparent from the following quote from Contact_4:

"We did the technical work of it in-house and then believe it or not we actually saw the buoy on the Discovery Channel. So sitting looking at this thing and: "Oh, that's an interesting sort thing", and it's huge, but it was originally designed as a missile launch space, so it's a huge buoy and it's got a top column on it and it's submerged. There are about two thousand of them worldwide and they've been used for oceanographic services and for missile launch and target practice and we discovered it was a company in [Area_8] that built them, so we kind of phoned them up and went and had a look." (Contact_4, End User_2)

This is not the only example of the acquisition of declarative knowledge from another industry by this organisation. Unlike the previous example which is clearly the serendipitous acquisition of knowledge, it can be seen to be based on an existing knowledge-base from a different industry sector. Additionally, the interviewee appears to identify the value of the acquisition of this knowledge:

"We do have lots of fun with chemicals. We play with anything. We're currently heavily into chlorine dioxide, and we're using that as a panacea for pretty much everything for getting rid or iron sulphide, for getting rid of H2S, for getting rid of bacterial erosion and bacterial action. So we've done quite a lot of that, but in order to get that to work we've actually built the technology again by ourselves. We've built a stable chlorine generating system, which we actually stole from the poultry industry. If you know anything about pigs and chickens, they are in these disease-free areas, and what they have is a chlorine dioxide generator that sprays it into the air as a mist and pushes it through either the chicken or pig sheds. And what that does is it kills all bacteria that it comes into contact with, and at 5 ppm concentration it doesn't do your lungs any harm or anything like that, so most of the chicken sheds and that run 2 to 5 ppm and you see this disease free stuff. Coming from a farming background we stole that and we built our own technology, and now we spike it into the oil phase and we use a fifth of the chemicals that we used to use. So that's another bit that we've been playing with.

That's a straight Opex saver but it has huge spin offs because we're only pumping in at 2ppm, and we're pumping into the water, and ultimately it will clean the reservoir out of H2S and the bacteria." (Contact_4, End User_2)

However in addition to using the enabling organisation as a vehicle for the acquisition of knowledge of new technologies (know what), the end user organisations can also be seen to use techniques such as the one identified in the following quote to gain an understanding of new technologies currently available as well as those only existing in a conceptual form. It is interesting to note that as well as an awareness of the technologies, Contact_7 also feels that there is an additional benefit of such activities in that it provides a degree of confidence with the internal technology screening process:

"But [Project_1] was one of the things that was mentioned at that open space forum, and it was one of the reasons we got some internal confidence that there were some great ideas out there. So it was one way for [Provider_2] to introduce it to our company directly, rather than through [Enabler_1]. I mean [Enabler_1] was at the meeting as well, and it was recognized that it came through [Enabler_1], but it was a chance to connect to people. The people that connected with [Project_1] in that instance were not the people who eventually used it, but it helps to generate some interest and confidence. If two or three people chime in to say: "Gee, that sounds kind of interesting" it gives you more confidence that you should screen it initially and that's probably what drove me to pick it as one of the top [Enabler_1] technologies in the first place." (Contact_7, End User_5)

Akin to a number of the other end user organisations, End User_5 can be seen to use a number of different channels for acquiring knowledge of technologies and as stated, subsequently increase their awareness and understanding of those technologies. What is apparent is that the route to accessing new technologies is, understandably, less important than simply gaining an understanding of the technologies and their potential applications within the context of the end user organisation. Significantly, the interviewee acknowledges two factors affecting the uptake of new technologies: on a personal level, the need for a dynamism is apparent in order to propose and support a new technological agenda, and the time in which to seek out new technologies; and on an organisational level the need for the end users to steer the direction of the enabling organisation in order to more fully address the agendas of the end users. This again emphasises the relationship between knowledge transfer and knowledge acquisition by suggesting that knowledge may be acquired by both parties through their engagement in a process of knowledge transfer:

"It's an issue I guess just to get people's attention, and we've got to have something that is operational almost, but I think [End User_5] is increasing its technology awareness. There are different camps within the company of course as like every other company. Some say that all the new technologies that are worth coming to us will come to us through vendors. Others say we've got to identify what we need, and go out and get them. There's probably something in between that is the right thing, but you've got to have a brave person and someone with a bit of energy to go get new technologies, because you've got plenty sitting on the shelf doing the old style. If you're going to try something new it takes a lot of energy and guts, and we're trying to encourage that the best we can, but in reality we're trying to get our job done. You can't say: "go ahead and take 10% of your time and look for new things." You can't do that. Hopefully you'll hear of something new and you're encouraged that the company encourages innovation, and you'll pick it up. But we don't have a specific program, or a specific budget, or a system, so that might be a limitation for [End User_5]. But on the other hand we have taken up a lot of technologies that might have been [Enabler_1] technologies that might have come through [Enabler_1], but might have come elsewhere as well, through a vendor, so however it gets to us. So I guess we need a little bit of two approaches. I think we should be involved with [Enabler_1] because we need to direct the [Enabler_1] direction because I do feel [End User_5] is different from some of the larger majors. We have different needs to other companies so we should be helping [Enabler_1] recognize that. That's why we need to be active." (Contact_7, End User_5)

Contact_4 however indicates a need for the enabling organisation to do more in relation to raising awareness of potential opportunities. However, like End User_5, the interviewee acknowledges the importance and value of having a dedicated resource within the organisation to focus on new technological developments and thus move from a reactive to a more proactive role in relation to acquiring knowledge of potentially beneficial technologies:

***"**I think it's really good for [Enabler_1] to bring ideas to you, but one of the problems is you park the idea and then you find an opportunity to use it to demonstrate the business case, and it becomes quite difficult if they don't tell you these ideas exist. You can't be out there all the time because normally we're out there, heads down, tails up, working away because we're working so hard. You need to take time to sit back, and take the time, but once you start getting technology tsars that sit within the companies, then you lose the ability because they are not looking at day-to-day operation and opportunity, so you have to work reasonably quickly."* (Contact_4, End User_2)

Contact_4 emphasises a need for active learning within the end users organisations in relation to identifying opportunities to apply new technologies. Aside from Enabler_1, the technology vendors and indeed the technology providers themselves, the role of other enabling organisations as a vehicle for the acquisition of knowledge relating to new technologies is also in evidence. However, although the end user can be seen to have been made aware of the technology provider via Enabler_9 and more specifically one of its awards, the engagement of the technology provider with Enabler_1 seems to have acted as a catalyst for closer examination of both the organisation and its technological capabilities by the end user:

"I think the first time I came across them was through [Enabler_9]. It was initially through their [Award_1] and we were invited to join the steering group. [Enabler_9] basically like to have some industry people so it was actually before they came to [Enabler_1] that we got a sniff of it and got some knowledge about it when they got their [Award_1]. Then when they came to [Enabler_1], we started looking at it more seriously. The particular thing that they wanted to do via [Enabler_1] was not quite what we wanted to do, but subsequent to their various discussions through [Enabler_1], we've had discussions with them as well, and then our bit has spun off, so as far as I know they are doing more work for [End User_1]. They've been doing some work for [End User_4]. They've done work for [End User_17] in [Area_19], and we're now launching some work of our own for them to have a look at various things that we'd like them to consider." (Contact_8, End User_6)

The interviewee went on to explicitly identify other sources of declarative and conditional knowledge other than Enabler_1. Although Enabler_1 can be seen to provide an awareness of only a relatively small amount of potential projects for End User_6, the interviewee acknowledges the value of the enabling organisation in acting to facilitate the initial contact with the technology providers:

"We see [Enabler_1] as one of our sources, what it is quite good at because of the way it's organized is getting other potential sponsors together in a group, but only about a third of the projects we sponsor come from [Enabler_1]. About two-thirds probably due to them being long-term relationships with the universities tend to just come in automatically. The thing that [Enabler_1] has the advantage of is it does give a focus point particular for SMEs. SMEs have a real problem getting their foot in the door of oil companies because we don't have the time. We would normally go to [Provider_8] or whoever and just say: "Go and find someone to do that." Whereas [Enabler_1], I would think the number of university projects versus the number of SME projects it has, the university component would be a much lower proportion.

So I think [Enabler_1] actually fulfils a very useful purpose from that point of view but it is not our only source." (Contact_8, End User_6)

Contact_8 seems to suggest an understanding of the variety of sources of knowledge relating to different aspects of the innovation process, and how these sources may be utilised by the end user organisations. Additionally, the interviewee acknowledges the variety of roles performed by enabling organisations in addition to acting as sources of information and knowledge (Azzone and Maccarone, 1997).

4.2.3.2 Knowledge Transfer and Dissemination

In line with the comments from participants from both the enabling organisation itself and the technology providers, the enabling organisation can be clearly seen to provide a valuable role in transferring declarative knowledge and awareness of both the technologies themselves ('know-what') and the procedural knowledge of the technology providers ('know-how') to the end user organisations. Again, the enabling organisation can be seen to provide value to the end users and the technology providers by making the initial introductions, after which both groups of actors interact independently of the enabler.

The value of the explicit knowledge of technologies transferred to the end users in documented form by the enabling organisation appears to be perceived as somewhat limited by the end users, as can be seen from the following quote:

"So [Enabler_1] have days where you can actually go and speak to the guy and see what he's trying to sell, because when you read it in the narrative it isn't particularly forthcoming as to what they are trying to achieve, and you don't see the means that they are going through to get this, or what the novelty value is of their tool. Although they say it is one particular tool to achieve something, it may just not be a suitable one because they don't have the depth of experience in the oilfield. That can be a problem. You have to go out of your way to attend these meetings to find this out." (Contact 6, End User_4)

This follows on from the experiences of the technology providers (as previously discussed in Section 4.2.2.3), who suggest that documentation relating to the technologies ('know-what') is requested by the enabling organisation following personal contact. Although the enabling organisation appears to facilitate the transfer of knowledge between the technology providers and representatives of the end user organisations, the end users themselves seem to utilise their own facilitators (who are in many instances the technology champions or the primary contacts for the enabling organisation). Contact_5 highlights a critical barrier to knowledge in transfer within organisations:

"What has happened with [Project_5] is this. My colleague, in charge of facilities related issues verified the effectiveness of a tool called [Project_3] and proposed to adapt this to a well. This proposal has been submitted to our committee for technology innovation, and that has approved the project. Now we have a budget for this project and we are going forward. What has happened in the meantime during this process has been integration between different disciplines. Despite this, many people do not have the willingness to speak to each other." (Contact_5, End User_3)

Although Contact_5 does not identify why this unwillingness to communicates exists (if indeed he knows why it exists), he goes on to emphasize the importance of the role of the specific project in integrating the different subject disciplines within the organization through appropriate interaction between individuals:

"This project has given us the opportunity to improve our internal integration process, and this has been possible because we had the right people in the right place. The key point of the idea is to move into the well something that was created for pipelines. Of course to adapt this tool to the well, the context is really challenging and more intriguing because if you have a robot, an autonomous robot, in the well, the limit of the possible applications is mainly your imagination. What has happened has been the need to involve other people working in the well context and production context. My job has been to get all these people to pull together, and to facilitate the discussion and the sharing of information and the objective." (Contact_5, End User_3)

Following on from the perspective of Contact_5, Contact_7 also emphasises the importance of networking in knowledge transfer, and the role of the enabling organisation in facilitating the networking process:

"*One of the things that I did was to hold an open space forum. It was called for technology and [Contact_1] was a big help in setting that up, and understanding how we might get different contractors and the mix of people we might bring to that. The whole theme to that was: "Let's consider everything and let's open our minds to different technology." It was a great success. I wish we could repeat it. I wish I was in that role now. We would repeat it but everybody is so busy right now it's hard to justify*." (Contact_7, End User_5)

However, as is apparent from Contact_8's comments below, once Enabler_1 has introduced the technology providers to the end users the two groups interact independently of Enabler_1's input:

"Occasionally also things will happen, projects move ahead, even say Enabler_1 acts as the introduction agency, but it might well particularly with the field trial ones move ahead virtually independently of [Enabler_1]. So after [Enabler_1] have made the introductions and then the companies may talk to each other directly. We don't purposely cut [Enabler_1] out of the loop, but then they have a finite resource as well and they are probably only too grateful that somebody picks up the ball and runs with it and they don't have to keep passing it from A to B." (Contact_8, End User_6)

Again, Contact_8 emphasises the need for both the technology providers and the end users to drive forward development projects, and also further emphasises the understanding of the end users of the primary function of the enabling organisation in identifying potential project participants, and facilitating their relationships.

4.2.3.3 Knowledge Storage and Maintenance

In line with the views of the technology providers in relation to the storage and maintenance of knowledge, the end users make few comments relating to the types or forms of knowledge stored in relation to the technological innovation projects with which they were involved. One interviewee does however identify one document provided by the enabling organisation which he helped to develop:

"On the [Enabler_1] website there is in effect a best practice guide to research projects which you can download. I have a vested interest in that because before I joined [End User_6] I was involved in compiling an awful lot of that, and they are basically lessons in terms of, not the technical side, but making a project run successfully. It was myself and a colleague that also had a lot of time involved in research projects, and seeing all the pitfalls of what goes wrong, and I believe that one of the things we actually say in there but probably more politely, is if it's an important project and it's a big project, don't let an academic run it. They are very good at doing research, very few of them are actually very good at running it." (Contact_8, End User_6)

Although previous sections relating to the acquisition and transfer of knowledge emphasise the role of explicit knowledge in documented form at various parts of the innovation process (notably the project proposals submitted by the technology providers to the enabling organisation), it is not clear from the perspective of the end users how or where this is stored. As such it is apparent that the end users do not see the storage of explicit knowledge as a critical knowledge-based activity in relation to the innovation process, or that this knowledge is codified in any formal sense.

4.2.3.4 Knowledge Creation

As Contact_5 comments, ideas for new technology may also be generated within the end users themselves, as well as the technology providers:

"My company retains a number of experts and professionals so of course they are generators of new ideas. The third one is what we call technology mapping coming from our sister companies world wide. We visit our sister companies and ask: "What are your needs?" For example, if you need to drill in 2km of water you need technology for that, or if you have a problem with the seismic imaging you need to approach the geophysics community."
(Contact_5, End User_3)

With regard to the relationships which exist between the technology providers and the end users, the end users not only support the knowledge creation process of the technology providers through funding the development of new technologies, but also through sharing knowledge of their technology 'gaps' with Enabler_1 who subsequently seek out organisations with the ability to close those gaps:

"We tend to have what are known as technology themes, so we have what you might call a vision which looks at what we need across [End User_1] worldwide, and certainly within [Area_11] locally, so there's two pieces to it. That is, what are the technologies? Where are the things that we have problems? So what technologies do we need to see develop in the industry in order to deliver solutions for what we can see? So on a global basis, one of them could be for example sand control because we've more and more of our wells becoming wells that have a sand production problem, so we need to have the technologies that one, can actually prevent the sand coming into the well wall in the first place, and secondly if the sand comes in, what are the remedial options that we can do?" (Contact_3, End User_1)

Similar to the perspective described within End User_1, Contact_8 states:

"There are specific areas that we would like looked at. Different oil companies have slightly different priorities depending on their key assets at the time. An example would be, [End User_6] has had a very big focus on its high pressure, high temperature fields over in [Field_15], but there aren't many of them, and ultimately we had to fund a lot of the work ourselves because other people said go whistle. We also have a big focus at the moment on extra heavy oil, for example the bitumens in [Area_6] because we operate in [Area_7] and we operate in [Area_6] and we're building our position further in [Area_6]. So these are higher business priorities for us whereas if you're [End User_5] for example, late life mature assets, trying to hit those funny little pockets that you've missed already are going to be much more of a priority for them." (Contact_8, End User_6)

The impact of these priorities identified by the end user organisations on the technology providers' ability to develop new technologies can be seen to be significant, as Contact_8 goes on to describe:

"If you have to prioritize your funding then it has to go with the top priorities and the top priorities are based on business needs. Now if you manage to get fourteen companies all with totally different priorities, then it may well be that the particular technology project will not go ahead, whereas other ones will go ahead with a particular group because it happens to hit a particular niche. Whereas other things we may need to self-fund ourselves because there isn't the appetite from others, and I mean there are other things that we'd be fascinated to watch and see what happens but we can't justify funding based on our current priorities." (Contact_8, End User_6)

However, this is not true for all the end user organisations, as Contact_4 describes:

"We tended to spend £20,000 a month on studies. Somebody would come in one month and we'd do a study on bacterial erosion on the pipeline. We used to use [Provider_27] in [Area_1]. The other thing that we'd do is if we had a Vortoil failure, we'd throw £20/30,000 at it. Now the tubes are only £5,000 each, and we'd break a couple and there are probably 300 of them. But you'd throw some money at that to see why it failed on the off chance that it will spin out something knowledgeable to us. Not even on off chance, but a better understanding the better we can operate it. But then the last time we had a tube failure we redesigned it to suit us, so we got a hold of [Provider_17] and changed their design to suit our particular positions because we found there was brittle fatigue. We were getting

harmonics set up and they were vibrating. So we designed a thing inside a honeycomb that it stopped it doing that, but again that's us having a requirement to go and do it but then the ability to go and chase it as well. A little bit different." (Contact_4, End User_2)

Due to the funding structure in place within End User_2, the organization can support the knowledge creation process of the technology providers financially and in addition influences the direction of the development of the technology itself. The end users then can be seen to provide a valuable source of conditional knowledge to the technology providers in identifying areas of application for the technologies:

"We tend to regard the innovation pathway as this 5-step process. Now we may have ended up it being only 5 steps because that neatly fitted onto the graphic and everybody could understand it. But it's really going through…And I've got a couple of examples that are within these of assessing someone has a bright idea. Will it work? So the first thing is to see, is this bright idea actually feasible? Now that may be mathematics and theoretical, it may be an experiment in a test tube but it's basically going to be, does the concept stand up? That may well be actually done within a university context by an MSc student or maybe a PhD almost at the university's or a research council's expense, but it's basically, does this bright idea stack up? After that the next step which I think that is still relatively fundamental research which may or may not get oil companies joining in, it may still be a bit early, is ok the idea works, but what are its applications? As an example if it works in air and water will it work in hydrocarbon, liquid and gas? Because obviously they are slightly different just as an example." (Contact_8, End User_6)

Related to this perspective presented by Contact_8, Contact_5 suggests that a successful outcome of a project is not only the development of a new technology. In addition, the identification of modifications to the technology itself which may improve its performance or lend itself to new context is also seen as important.

"The principle has been proven for this project and we are in the final stage, but the important thing in what has happened has been the idea to adapt this tool to another context and this idea came from [End User_3] or perhaps from the other members." (Contact_5, End User_3)

The importance of the role of the workshops run by Enabler_1 as an opportunity to voice these technology gaps which subsequently influence the development of specific technologies by the technology providers can be seen from the following quote from Contact_3:

"On a more local basis, certainly with [Area_11], we have funding that supports the [Enabler_1], because the [Enabler_1] is seen as a means of collating information in the sense of the workshops that they run earlier in the year, which we find to be extremely valuable because they give us a chance to sit in on those workshops and input what we feel are the technology needs or gaps, or where the problems are. We are also sitting in on the workshops with operators and other major service companies that are obviously putting in their requirements." (Contact_3, End User_1)

Thus, Contact_3 reinforces the importance of the transfer of knowledge between the actors involved in the innovation process, and highlights the relationship between knowledge transfer and creation.

4.2.3.5 Knowledge Application and Exploitation

In a number of instances, the end users can be seen to wish to be closely involved with not only the technology providers, but also other end users who may apply their own knowledge to the development of a new technology:

"*Because there are certain partners who are very good at coming forward and are very intimately involved in driving a project forward, and then there are others who put the money in and then don't take any further part. Certainly from [End User_1]'s point of view we want to be in projects with people that are really keen and interested and put their input in and not just put the money up because it's only by having that cross-knowledge of, you know, what are you looking for in your solution, and what are we looking for in order that you can steer that project to come to something rather than just put money in and let the companies do what they want, and come up with a product which might at the end of day....Well yes it's a nice product, but it doesn't do what we wanted it to do."* (Contact_3, End User_1)

However the degree to which the end users may involve themselves with a specific project can be seen to be dependent on the different skills and areas of expertise (the procedural knowledge) of the technology providers:

"So it varies depending on how much we feel we need to get involved with and how much we feel they can run certain parts of the project quite happily themselves because that's where

their forte is and our steer is maybe more into what the end product has got to be, it has to be something that will sell and stand in the marketplace." (Contact_3, End User_1)

Specifically in relation to their involvement with Provider_3, the interviewee from End User_1 goes on to identify the types of knowledge which they applied within the development process:

"In terms of the development of the technology, with [Provider_3] we weren't much involved with the actual design of the seal because obviously [Provider_3] had done a lot of work on that beforehand, and knew the limits. We were more involved with telling them: "These are the type of wells we want to run them in, and these are the type of pressure tests that we want them to hold, and this is how we want them deployed." So we were giving them more of the steer on the practical aspect of, "the product that you provide is going to have to work here, so you need to make sure you can achieve that", rather than in the applications." (Contact_3, End User_1)

Clearly, End User_1 felt there was less of a need to share and apply declarative knowledge of the technology and its procedural knowledge of its development process ('know what' and 'know how' knowledge types). However they can be seen to apply their conditional knowledge in relation to the contexts within which the technology would be applied ('know where' and 'know when' knowledge types). Similarly, End User_6 identifies the importance of a project team with complimentary skills, not just those relating to the development of a new technology. This can be seen to be particularly true in situations (as described below) where there are multiple project partners:

"Because of the complexity in terms of the number of institutions and the number of sponsors, the good thing is that it does have its own project manager. It's not being run by an academic. It has, in effect if you put it in business terms; it has a project manager and a technical manager. Now the technical manager is the senior academic. Then there is a project manager who looks after all the coordination, making sure things like contracts and invoices are sent out, that calls for meetings are sent out, that all the various deliverables are distributed, etc. Basically the guy that does all the legwork, but the important legwork to make sure the thing happens." (Contact_8, End User_6)

The importance of applying appropriate procedural knowledge and expertise within the innovation process is not only acknowledged by the end users. Contact_8 goes on to suggest that the technology providers also acknowledge its importance, and proactively seek out to fill these gaps in capability (Leonard, 1998):

"There are a number of occasions, and not simply with academics but also in some cases where SMEs use third party companies as, in effect, jobbing project managers, because SMEs may not have the resource to be able to do it but it's not just SMEs. I know one particular company that uses the third party project manager because it doesn't want to be bothered doing it itself and it feels it's more cost effective to pay people who are doing it all the time to do it and fine." (Contact_8, End User_6)

More generally, the end users can be seen to apply their conditional knowledge of the industry ('know where') in terms of the potential application areas for new technologies, both geographically as well as technically. However the opportunities for the end users to apply this knowledge and to share it with the providers can be seen from Contact_7's perspective to be limited, and again indicates the need for the development of a common language in order to facilitate learning:

"The initial problem that I saw with the technology is just that [Provider_2] very well knew what the tool was and what it could do for them, but they didn't quite understand what it could do for operators, and that's the typical conundrum isn't it? We know what we need but how do we explain that? Who has the time to explain it to anybody else, and what we decided to do was take the technology and look at it closer. I liked the idea and the words they were saying. It would reduce costs and environmental impact and so on. It all sounds very good, but are they realistic, and do they apply to our cases? Short of having an immediate application for it, a well that was specifically a dream Project_1 well and getting the engineers on that project all excited about it, there's no way that we would be able to bring on that technology." (Contact_7, End User_5)

However, where these opportunities to transfer knowledge of technological need from the end users to the technology providers have been successful, they can be seen to lead on to the application of the knowledge of the end users in relation to potential application contexts for the new technologies. As is discussed in section 4.3.6 (knowledge valuation and measurement), the end users are naturally interested in technologies which can be applied globally, but the legislative environments in different areas can be see to affect how technologies may be applied by more than one end user:

"The application of the metal-to-metal seal is global. There's not the pressure elsewhere in the world, although integrity is a key issue if you go to the [Area_14], [Area_1] and in the lower 48 is a very important key. If you go to other places in the world legislatively there's not the same push, but internally we have standards that say: "This is the minimum integrity that we will accept to operate." In certain parts of the world our standards are considerably above what the legislative standard is. So we stay with that standard, as do our competitors, rather than drop it to whatever the local standard is. So although we can see things for the metal-to-metal seal in [Area_11], and I'm sure that product will grow and go elsewhere once people see it is available, I don't think there would be the drive elsewhere to develop it. They would have said: "Well why do we need metal-to-metal seals on plugs? We've had standard oilfield equipment which still works extremely well. There's no reason why we shouldn't use it. Why would we use something that costs considerably more money when we can use something that we've already got?"" (Contact_3, End User_1)

The different priorities and perspectives presented by the End Users can also be seen to cause problems for projects which present solutions to issues which are geographically specific, and as such may not be of interest or benefit to all end users:

"The one thing and again it's not [Enabler_1]'s fault, but a lot of oil companies tend to come with a very, [Area_11] perspective whereas certainly us, [End User_3], are coming with a much more global perspective. We want to be able to use these things in the work, the research centre here is a corporate resource and not an [Area_11] resource, we just happen to be in [Area_11]. So that does also occasionally get with this problem of prioritisation because what [Area_11] subsidiary of an oil company is going to be interested in bitumen? No-one, whereas we're always on the lookout for technologies to do with that because we have places we want to deploy them. So we do occasionally…our moan would not be so much about [Enabler_1] but more about some of the other participants being much too narrow so we're bitching about our fellow participants rather than [Enabler_1]." (Contact_5, End User_3)

Even within the end users themselves, due to their global coverage, their knowledge of their own technology priorities can act to hinder the development of technologies which while relevant may not have as broad a number of areas of application:

"*But of course they are looking for example to maybe say in [Area_11]: "You have a particular problem" and then you say: "OK, we'll tell you what that problem is. We'd like you to fund some development to actually solve that problem." They look at that and go:*

"Well yes, that's pretty good, but in actual fact [Area_12] have this problem over here, and [Area_13] have the same problem, and [Area_1] has the same problem." So what they require is going to have a larger pull on our funds than you, because you're just one area in the world that wants this solution. Whereas we could fund something that could give a solution to three areas of the world, so although people around the world are saying these are the technologies that we need, they get ranked because obviously there is a limited pot of funding." (Contact_3, End User_1)

Clearly then for the end users, some balance is required in identifying and developing technologies which may have a global application and those technologies which are more appropriate to a more localised context:

"So us in [Area_11] are looking at what our vision would be for say 2015 and some of the work that has been worked on would be centrally funded but we're also looking to see what's happening locally and what things are possibly going to be developed by local companies which might be a solution to what we require. We are also looking at what are the things in the short term? What are the things that are going to be developed within the next 18 months to 2 years?" (Contact_3, End User_1)

As well as the more localised perspective on the application of new technologies shown by the technology providers, the end users in many cases have a broader, more globalised perspective. Although this knowledge may benefit the technology providers by identifying other areas where they may apply technologies, it can be seen to impact on the levels and methods of funding the development of these technologies.

4.2.3.6 Knowledge Valuation and Measurement

Related to the funding issues noted above, due to budgetary constraints the end users prioritise those technologies which will give the greatest degree of benefit to the organisation, as Contact_3 describes:

"…we could fund something that could give a solution to three areas of the world, so although people around the world are saying these are the technologies that we need, they get ranked because obviously there is a limited pot of funding. They are ranked to see which are going to be the biggest delivery. If we are going to be successful in delivering those

technologies, what gives the biggest bang for the buck from within [End User_1]? So we have those themes to work with." (Contact_3, End User_1)

Similarly another interviewee notes that although the declarative knowledge of the technology experts within End User_3 was critical in identifying potential new technologies, it was essential for the technologies (and indeed the providers of those technologies) to demonstrate their value before any funding could be secured:

"The person that can say: "This is useful, this tool or this idea could be useful to us" is our expert but this is not enough in our company, you have to consider that any action comes from a number of initial conditions. If the number of initial conditions is satisfied then you can go on." (Contact_5, End User_3)

However, Contact_5 went on to describe the difficulty for the technology providers in determining the value of the application of new technologies:

"The correct evaluation of the impact that an idea can have on our business is not such an easy exercise because sometimes the researcher doesn't consider the question very deeply. The idea can be a very brilliant idea, but if there's no impact, or if the benefits aren't well defined we can't proceed on that route. To increase the knowledge is not an objective unless it permits you to increase your production/reserves or to get better results." (Contact_5, End User_3)

Clearly then, it is both challenging and vital for the technology providers to determine the potential value of their technologies if the end users are to fund and support their development. The importance to the end users for the technology providers to construct a valid business case for the development of a new technology (and as part of this process, to determine the potential value of that technology) is described in the example given by Contact_4:

"…the only one that we were funding that we kind of stopped funding was Project_3. We were quite impressed with that, but then they came and started looking for $400,000, and once you get into that you need to prove a business case. It would have been better if they came out of it and said: "Give me a million" and we'll say: "This is what we'll get at the end of it." We could have funded that. What happened is once you get over $400,000, because it was an R&D project it required the next level of signature above mine because it wasn't a business case. I couldn't build a business case because they couldn't offer me any discounts

in the future, and I didn't have any priority over it and didn't have any rights to the tools. So the argument comes back, if you don't pay, somebody else will, and it will come anyway. Whereas if they'd come and said: "Give me a million pounds, or one and a half millions pounds, and I'll give you a tractor and I'll do five tractor jobs for you in the pipeline for the next three years." I could have made a business case and signed it off no trouble, but I couldn't sign $400,000 off because there was no business case, so I couldn't demonstrate a value to the company in doing it because the argument was, what are we going to get from it? Access to this technology, but if we don't spend into it ultimately we'll get access to this thing." (Contact_4, End User_2)

However, once a technology provider has proved a business case for the development of a new technology, there can still be accompanying issues surrounding the use of the technology, and indeed the ownership of the intellectual property:

"I think the difficulty where confidentiality comes in is where you're developing something new from scratch, and who owns the IP. Of course a small company that is building something that has come up with an idea, they are very protective of wanting to create that IP. One of the difficulties you have when you come to fund things, you look at the contract you have to sign and you think: "I'm going to put in £50,000 here", which to us is not a lot of money, well it still takes a lot of effort to get £50,000, but to a small company getting £50,000 times four, that's huge amounts of money to them. So you're thinking: "What am I going to get out of £50,000? What rights have I to use this IP elsewhere?" That's often where the difficulty comes in that you want to support the company, but you don't want to tie yourself into the position that three years from now if you develop something you can't use that knowledge elsewhere having helped fund it." (Contact_3, End User_1)

While the perspectives of the technology developers in relation to the valuation and measurement of knowledge can be seen to focus on the ownership and protection of their intellectual property, the perspectives of the end users (as described by Contact_3 above) can be seen to relate to the rights of the end user to use that intellectual property in different contexts.

4.2.3.7 Summary of Key End User Organisation Findings

Process	**Findings**
Knowledge Acquisition and Learning	The enabling organisation is seen by the end users as a vehicle for declarative knowledge acquisition in specific contexts.
	The enabling organisation needs to have a good understanding of both the technical themes and the business drivers of the end users.
	The enabling organisation regularly acquiring knowledge of the technology needs of ends users was seen as important due to their changing priorities.
	End users acquire declarative knowledge from other sectors.
	Industry events provide the end users with opportunities to acquire declarative knowledge.
Knowledge Transfer and Dissemination	The end users value the role played by the enabling organisation as a conduit of declarative knowledge.
	The end users acknowledge the importance of networking in knowledge transfer.
Knowledge Storage and Maintenance	It is unclear what explicit knowledge is stored by the end users, or how it is stored.
Knowledge Creation	End users both support the knowledge creation process of the technology providers, and identify scope for new technologies.
	The technology priorities of the end users drive different areas of funding for the technology providers.
	The processes of knowledge transfer and creation appear to be closely related through industry events.
Knowledge Application and Exploitation	The end users benefit from the application of knowledge by their peers.
	The involvement of the end users within the innovation process is dependent on the procedural knowledge of the providers.
	End users apply their conditional knowledge to the development process to contextualise the use of the technologies.
	Technology providers use the apply the knowledge of third party organisations where they have gaps in capability or expertise.
	The global and local contexts within which technologies may be applied affects their funding and development.
Knowledge Valuation and Measurement	End user prioritise technologies which will give the greatest benefit to the organisation.
	The value of technologies must be demonstrated by the providers prior to funding by the end users.
	Ownership and usage of IP may be present issues even after development.

Table 22: Key End User Organisation Findings

4.3 Findings: Part 2

Following the development of the web-based narrative system, its subsequent loading with the interviewees' narratives and viewing by the participants, the participants were interviewed for a second time. This section presents the perspectives of the interviewees following their use of the narrative system as they relate to the knowledge-based processes, forms and types of knowledge used within the technological innovation process (Section 4.3.1) in order to determine how the actors are influenced by exposure to the explicit knowledge of other actors; and their perspectives on the content, structure and interface of the web-based system itself (sections 4.3.2 and 4.3.3).

Like the previous section, the findings have been structured around six knowledge-based processes. The data can however also be seen to relate to generic observations relating to the innovation process, the specific interactions between different groups of players, and the reflections of the interviewees on their own experiences.

4.3.1 Knowledge-based Processes in the Technological Innovation Process

4.3.1.1 Knowledge Acquisition and Learning

One interviewee from an end user organisation notes the reduced need for the involvement of the enabling organisation as a source of procedural ('know how') knowledge for end user organisations relating to the engagement between the different groups of actors within the innovation process:

"It depends how many players are involved if it's a good model or not. We seem to have quite a lot of common ground with [End User_16], because they're more slack with the purse strings possibly, and we seem to have the same kind of ideas at the end of it, so I don't think there's any need for any guidance from [Enabler_1]." (Contact_6, End User_4)

However, the same interviewee also suggests that there is an increased role for the enabling organisation as a source of procedural knowledge from which the end user organisations may acquire knowledge in situations when there are more players involved in the process:

"Possibly if there were four or five different players, then a format so you knew where you were, there was an agreed path through it might be of more importance, because I can see people losing the plot or saying: "Why didn't you consult me about that?" There's more room for a bit of a screw-up between all the major companies. So if there are only two people, I don't see a problem. But I could see a problem if there are more players because it's more complex." (Contact_6, End User_4)

Although Enabler_1 aids technology providers by identifying potential end users of their technologies and establishing and facilitating their relationships, one interviewee from a technology provider organisation also highlights the potential threat of other technology providers acquiring declarative knowledge of technologies through their engagement with the enabling organisation:

"I think that small companies rely on [Enabler_1] and the operators form a relationship, and that's all very confidential, but if you develop a new technology and your competitor can see it from a very early stage, they can (if they think its a good idea) throw money at it. Big funds straight away and develop it very quickly. Whereas we are still having to go through the whole [Enabler_1] process which can take a year or something before you get any kind of funds for it." (Contact_11, Provider_3)

The same interviewee also suggests that the potential threat outlined above to the technology providers may also have an impact on the potential end users of new technologies, as fewer technology providers may be inclined to use Enabler_1 as a route to market if other technology providers are able to acquire declarative knowledge and procedural knowledge relating to new technologies:

"I think the oil companies will continue because the annual fees are not that high, but I think they will probably have less new technologies coming in. I can't put a new technology in and show it at that early stage to [Provider_8] or [Provider_9]. Even though they are bound by their agreement with [Enabler_1] they could easily say they already have something like that." (Contact_11, Provider_3)

One interviewee from an end user organisation also echoes similar concerns. However the interviewee goes on to suggest that, although the technology providers may have concerns regarding the protection of their intellectual property, there may also be instances where more than one similar type of technology reaches the market at the same time. Additionally, the interviewee suggests that the confidence of the technology providers in using the enabling organisation might develop if the enabling organisation is not seen to be providing other technology providers with unprotected declarative knowledge:

"It depends on how [Enabler_1] handle it, if they start to see that there are concerns from the SMEs that this might happen and if they can't allay those fears then that might be a danger. They might just say: "We are not going to put the technologies in through the [Enabler_1] anymore." On the other hand, if they don't see that, and the small companies start to see technologies coming in that [Provider_14] etc don't pinch the ideas or in their view, its subjective, in the sense that you think that someone has pinched your idea but in actual fact they haven't pinched your idea because they were already working on it but just hadn't made it public because they were keeping things to themselves as well. Then suddenly you put your idea forward and they put their idea forward in a similar space of time and say: "Well hang on a minute, we went in to this with the [Enabler_1] and these people, because their members have seen it have just gone their own route and stolen our technology." So there is always that kind of conflict that is there. If people don't see that, or don't feel that is happening because these companies have been present within the [Enabler_1] for a period of time and the small companies are still getting their technologies adapted, taken forward by the operators then it will just build the reputation of the [Enabler_1] as a means of getting things brought forward and it won't be a blocker." (Contact_3, End User_1)

However, the issue of acquiring declarative and procedural knowledge relating to confidential or commercially sensitive material between end users can be seen to be quite different from the technology provider's perspective shown above:

"If a person can get connected with another person one on one, they talk to each other. Let's say it's two end users now, myself and another oil company representative, get together and we share an interest in a project, and I can learn from his and he can learn from mine, I'm going to give him that hard data and he's going to give me his potential data, and we're going to swap that easily. It doesn't hit the world, it doesn't hit the public, it doesn't hit all the things, and we trust each other to keep it confidential. So I think that's a better way to connect people. Connect the individuals who have common interests first, don't just throw the data out on the internet or wherever else people can find it." (Contact_7, End User_5)

Critically, the interviewee highlights the importance of common interests in technology-based projects between end user organisations, and of trust between those providing and acquiring declarative and procedural knowledge. The interviewee also emphasises different approaches in managing knowledge in various forms, and also illustrates the closeness in relationship (as identified in sections 4.3.1 and 4.3.2) between knowledge acquisition and learning, and knowledge transfer and dissemination.

4.3.1.2 Knowledge Transfer and Dissemination

The importance of understanding the personal contexts and perspectives which surround the process of technological innovation (and consequently affect the knowledge which may be transferred within the process are further emphasised by the following quote from Contact_7, who suggests that it is the individuals involved in the process, and the relationships which exist between them which act as a catalyst for the success or failure of the development of a new technology:

"So the idea I think behind the work that is the mechanism of people, the chemistry of individuals. When it happens it takes off. And to me it just emphasised that you just have to get those individuals together, because where it worked, that's what it was. So I think these things go hand in hand." (Contact_7, End User_5)

This perspective on the value of personal relationships as enablers of knowledge transfer is shared by another interviewee from an end user organisation, who states:

"The fact that word of mouth, or making that connection or people having a problem but talking somehow to someone else who just happened to say: "Oh, I know another company who has been working on something similar to that. Why don't you speak to them?" Suddenly the connection was made, and shortly afterwards they'd actually got a working relationship together, rather than them going off on their own, and trying to find a solution themselves, when actually one already existed. That was a good piece of learning for me, out of the information you had, I can tell you." (Contact_3, End User_1)

Similarly, an interviewee from a technology provider emphasises the difficulty in maintaining relationships between individuals in both the enabling organisation and the end users, and notes the effect this may have on the development and consequent application of technological innovations:

"If you build up a rapport with people, then when they move on, you've got to start all over again. But like I said our involvement with [Enabler_1] has been quite minimal since then so I'm not sure if that's had an effect for us. It just hasn't been relevant to us at the moment,

going the [Enabler_1] route. Apart from the fact that there is this one project that's still slowly moving forward." (Contact_14, Provider_6)

Additionally, Contact_7 identifies the role of serendipity in not only creating the links between the technology providers and the end users, but also of matching the technological needs of the end users with the capabilities of the providers:

"I think the stories of the providers and end users are both are pretty important because it's where the two don't meet that's such an interest, isn't it? Where things don't happen. I just remember the biggest impression is how lucky it is that an end user and a technology provider ever meet, because everybody is coming and going. It's so temporal, it's so individual to circumstance, that it's amazing anybody gets together. So to read somebody's experience doesn't mean to me that represents the situation, it just represents that experience. My experience was probably fortunate in some ways in that it coincided with our need and somebody else's requirement or ability met. But I think it's also taking that little extra step to provide something - a little bit of faith to do something, and you can only do that so often in so many places. Perhaps we were lucky to have found that in itself." (Contact_7, End User_5)

Contact_7 does however acknowledge the important role of Enabler_1 in facilitating the introductions between the technology providers and the end users, and in acting as a transfer agent for declarative knowledge. Once again however, the interviewee emphasises the need for the players to drive forward the process at a personal level:

"It's not a mechanistic process, and that was exactly the case for us. We had the introductions, but really...And then [Enabler_1] again tried to give it some momentum, but really if we hadn't decided to do something as individuals, it wouldn't have gone anywhere. So there is a place for [Enabler_1] to introduce things, to get people together, but after that it's got to have its own chemistry or it won't happen." (Contact_7, End User_5)

From the technology providers' perspective, the role of Enabler_1 in providing an introduction to potential end users of their technologies appears to be highly important. However, as stated in section 4.2.1.1, after reading the narratives of other providers several of the technology providers identify significant risks in relation to sharing declarative knowledge of their technologies to their competitors by using Enabler_1 as a potential vehicle to market. This view is also identified as a risk for the technology providers by an interviewee from one of the end user organisations. However, the interviewee also acknowledges that although some of the smaller technology developers may have concerns about exposing their technologies to their larger competitors this may be unfounded, and in fact there may simply be similar technologies developed at the same time coincidentally. The interviewee also notes that if the enabling organisation can manage the concerns of the smaller technology providers, then this in fact may help to build the reputation of Enabler_1 as a successful route to market for the technology providers:

"I think that [Enabler_1]...If they start to see that there are concerns from the SMEs that this might happen and if they can't allay those fears, then that might be a danger. They [SMEs] might just say: "We are not going to put the technologies in through Enabler_1 anymore." On the other hand, if they [Enabler_1] don't see that and the small companies start to see technologies coming in that [Provider_14] etc, don't pinch the ideas or in their view...It's subjective in the sense that you think that someone has pinched your idea but in actual fact they haven't pinched your idea because they were already working on it, but just hadn't made it public because they were keeping things to themselves as well. Then suddenly you put your idea forward and they put their idea forward in a similar space of time and say: "Well hang on a minute, we went in to this with [Enabler_1] and these people, because their members have seen it have just gone their own route and stolen our technology." So there is always that kind of conflict that is there. If people don't see that, or don't feel that is happening because these companies have been present within [Enabler_1] for a period of time and the small companies are still getting their technologies adopted, taken forward by the operators then it will just build the reputation of [Enabler_1] as a means of getting things brought forward, and it won't be a blocker." (Contact_3, End User_1)

However one interviewee from an end user organisation challenges both the validity of the enabling organisation in relation to short-listing technologies on behalf of the end users (and consequently deciding what declarative knowledge will be shared with end users), and also the ability of the technology providers to transfer declarative and procedural knowledge relating to the ability of their technologies in meeting the needs of the end users:

"If [Enabler_1] are doing the whittling down process, are they the best guys to do that? If they've got a hundred projects and they take it down to ten...There are usually twenty projects a year which come up, but I don't know which other projects have come up beforehand. I'd hate to think that they were knocking something out that might have one application maybe, but would save a bunch of money, or maybe they didn't fully understand what the guy was trying to convey, because a lot of these guys are not actually very good at trying to explain what they're trying to do. So that might be a thing that we need to have a look at."
(Contact_6, End User_4)

The narratives can also be seen to provide an opportunity to reflect both on the process of involvement with Enabler_1, as well as the perspectives of peers (in relation to the technology providers as well as end users) and also the perspectives of other groups of players. Notably several of the interviewees identify the difficulties experienced by the technology providers in Enabler_1 acting as a conduit for the transfer of knowledge, and indeed in their direct engagement with the end users as can be seen from the following statement by a representative from an end user organisation:

"Yes, it came across quite strongly, maybe the frustration that some of the developers have with [Enabler_1], not with the organisation itself or the facilitation they do but just that it takes a long time, and that's not [Enabler_1]'s fault because they are relying on the operators coming back in and saying: "Yes, I'm interested in this." They'll always most probably get six or seven coming in that will say: "Yes, absolutely interested in this, let's have a presentation." And then when you get down to it, it's down to 3. Then, even if they have all the operators saying they are going to go for it, it then takes ages to get though all the legal departments, and the contracts signed, and then the payments made. It can take twelve months from: "This is our idea, we need support to develop it" to actually getting the project kicked off. So that is a frustration I can see that a lot of developers have. I think that it is a frustration that [Enabler_1] have as well, you know, twelve months later and you still haven't got things going having put a lot of effort in." (Contact_3, End User_1)

Despite the frustrations of all the groups of actors relating to the timescales of development projects, one interviewee from a technology provider does however acknowledge the importance of the enabling organisation in maintaining the relationships between the technology providers and the end users:

"We've only had one submission to them which is actually ongoing. It kind of stalled a little bit, but I wouldn't say that was particularly because of [Enabler_1]. It was involving three oil companies. It was really just getting all three to work at the same time. Right now there are two that are interested, and we may just go with two. But that's stretched out the process a little bit. Six months after, you kind of lose a bit of momentum with it, so it becomes, well, it's out there, but we're not pursuing it like we were. But just recently that project is actually getting a little more momentum, so we are actually talking to the oil companies, and I think they're going to be talking to [Enabler_1] because it's still an [Enabler_1] project. So just to summarise, there's been very little happen since then to be honest on the [Enabler_1] front

apart from this one project that is really taking a while to take forward and happen." (Contact_14, Provider_6)

As can be seen from the following quote from the interviewee from the enabling organisation, the management of the expectations of both the technology providers and the end users is an important part of the overall process in relation to the outcomes of the technology development as well as the engagement with the process itself, and suggests an explicit need to transfer both procedural and conditional knowledge between the providers, the enabler and the end users:

"...if one message to come out of it was perhaps it takes a long time or takes longer than perhaps the developers thought to get to the end point then, that was one thing. I think a lot of it comes down to their expectations at the outset, what they had expected the process would be like, how long it would take and what they would get out of it at the end. Some, because of how their business is structured or whatever, may have different business drivers from the others so it may be more time critical for them than for others, because of cash flow or whatever else.'"(Contact_1, Enabler_1)

Reflecting on the narratives of the technology providers, the interviewee comments:

"I think the feeling I have is that people have different views in how successful the interaction is, and what they can get from it and some may have expressed frustrations that things that took longer than they thought, on the other hand some were complimentary about the assistance they got from the process. So I guess there weren't any great surprises in that. My own view is that people get...Their outlook is conditioned by the success or otherwise they have experienced." (Contact_1, Enabler_1)

In addition to enabling the interviewees to reflect on the perspectives of other players within the innovation process, the narratives also provides the players with an opportunity to reflect on ongoing changes within the technological development process itself, as facilitated by Enabler_1. Following on from the above statement by Contact_1, the subsequent statement by a representative from one of the technology providers can be seen to show some of the frustration of the technology providers in relation to the timescales of the development projects affected by the application of new forms of procedural knowledge by the enabling organisation:

"The other thing they have done now, [Enabler_1], is that they have taken more control of the contractual side. In the past, it used to be an [Enabler_1] contract which was issued and then, to get it finalised, the developer dealt direct with the funding party. Now they have taken more of a stance to say: "This is a contract and that's it, no changes." It causes a delay in signing off contracts. The one we are doing right now, the initial contract was issued in February or something and it took until July really to get it finalised. Which is a long time, and it's only after about 3 months that I said: "Well, I'm going to take control now", then things speeded up pretty quickly." (Contact_11, Provider_3)

The frustrations experienced by the technology providers in their engagement with the technological development process are however not solely attributable to the enabling organisation itself. Indeed the following interviewee acknowledges the failings of the end users in transferring causal, conditional and declarative knowledge to the technology providers:

"It's incumbent on us the operators to...You can't lead people on. You have to be either brutal and say: "Sorry, your technology is not of interest to us. Don't waste our time any more on that one; we're not going to be interested in it." But where you do say you're interested, follow up as fast as you can. So yes, there's a learning for [Enabler_1], there's a learning for us as well." (Contact_3, End User_1)

Expanding on issue of the difficulties for technology providers in relation to the timescales associated with using Enabler_1 as a facilitator, Contact_3 uses the narratives as a way of confirming personal understanding of a specific context, and indeed as a justification for seeking solutions to perceived issues:

"So I think that came across in the fact, yeah, I realise there is an issue out there about the SMEs bringing their things through and therefore there's an issue about the [Enabler_1], but I don't know a better way of doing it. It's just something you've got to be aware of, and I think it's something as an oil company that if we say we're interested, we have to get back to people very quickly and say: "Yes we are going to fund this"' so that at least they know we're on board rather than saying: "Yes, I've had ten companies say they're interested, it's six months later, and ten companies are still out there saying to me we might be interested in funding it." I think that to me, that it confirmed that this is an issue that [Enabler_1] have, and we need to do something about it, because it does reflect badly on them and from the person trying to get their technology brought to market, you know we might as a company be saying: "You need to use the [Enabler_1] because we've got funding we can put through the [Enabler_1]", and

they're basically saying: "No, I don't want to use [Enabler_1] because I know it's going to take me twelve months before we'll actually get to product. What I actually want is [End User_1] to sign up now, I want [End User_4] to sign up now, I want [End User_11] to sign up now, and if I get three of you then fine, we'll go and do it." And we're saying: "Well no, you've got to go through [Enabler_1] to do it as a route of getting things in to us." (Contact_3, End User_1)

Again from the perspective of the end users, Contact_6 acknowledges the different roles undertaken by the technology providers (and consequently the different types of knowledge transferred to the end users relating to different aspects of the technologies) in their attempt to match their technological offerings with the needs of the end users. Additionally the interviewee can be seen to recognise the need for declarative knowledge in the identification of the appropriate contacts within the technology providers:

"What was quite interesting was one of the providers it was, but they seemed to wear different hats for different companies and portray different parts of a technology in order to make it workable. That was interesting, because we don't see that side of it, you know? You've almost got to see how a company ticks before you can pitch it at the right angle. It's been quite good from the companies, in that it seems to be the same guys who are in position for quite a while now, and that's quite a good thing I think, because you know who the contact is." (Contact_6, End User_4)

Echoing this sentiment, Contact_11 recognises the importance of the end users personal declarative knowledge, and the relationship between the explicit declarative knowledge as presented by the enabling organisation, and the tacit knowledge of the end users:

"...if they get hundreds of proposals, they have to somehow vet them and choose the ones they like...I think the first time is really hard to get through the [Enabler_1]. I think once you have done it once and delivered something, the operators know you and will contact you directly and say if they think it is a good idea or not. That's what I had the second time around. Operators that had received the form had some additional questions and just phoned me direct because they knew me." (Contact_11, Provider_3)

This need for declarative ('know who' knowledge) is also identified by another of the interviewees from an end user organisation. In this instance, the interviewee acknowledges its value, not in relation to procedural knowledge in the form of the capabilities of the technology providers, but in relation to the provision of existing technologies (declarative knowledge) which may be applicable within another context:

"The other piece I found of interest when I started to read through some of the dissertations if I can call it that was the fact that ideas came in often from a brainstorming idea. People talking came up with a possible way that they should work forward, and then it was in carrying that forward, it was: "Hang on a minute, so and so over there has been working on that project", or "there's something similar in a totally different environment, totally different maybe industry but they've maybe got a solution for that" and then, "Oh well, if they've got a solution for that then maybe that's applicable" and making that connection, making that call, and finding out that it was actually applicable, it just needed some changes, but suddenly we didn't have to do this huge piece of this project because this bit was already done. You can skip the development stage, or whatever. That was very powerful." (Contact_3, End User_1)

As stated above, the narratives not only provide an opportunity for the interviewees to reflect on their own perspectives, but also to reflect on the perspectives of other actors. As such, the narratives can also be seen to provide some degree of reassurance to the technology providers in relation to the engagement with the enabling organisation by their peers:

"I read some of the other stories you had in there and it seemed very similar to what I had said myself. I thought it was a good thing, it was clear what technology providers think of it." (Contact_11, Provider_3)

However, although the opportunity to develop a better understanding of the relationships between the technology provider and the enabling organisation is seen as beneficial by Contact_11, the interviewee from Enabler_1 challenges the extent to which this understanding may be transferable to other personal or organisational contexts, and the effect this may have on the procedural knowledge of the actors within the process:

"I think you would need to perhaps spend more time understanding what the key messages were from all of that. There were a lot of things which were I guess relevant to that individual or relevant to that organisation, but you would have to distil from that what messages you could take that might have an impact on say the processes we use or ways of operating." (Contact_1, Enabler_1)

Further expanding on this issue Contact_1 suggests that although the enabling organisation may transfer procedural knowledge to the technology providers through their engagement, this knowledge may not in fact be reusable due to the different forms of interaction which are possible with the enabling organisation:

"If they have been through the process once as it were with a particular technology, they would then have that experience if they are coming back again to [Enabler_1] or another enabler. They would have that experience to know...How transferable their experience is to another provider, I don't know. Each one might be slightly unique. It may depend on what kind of support they were seeking, so if they were looking to do a technology development it's probably a different form of interaction with [Enabler_1] than if they were doing a field trial or something like that." (Contact_1, End User_1)

Conversely, the following interviewee from an end user organisation supports the views of the technology providers, and highlights the importance for the technology providers in acquiring knowledge about the experiences of their peers:

"...it's a great piece of learning for them. If they can look at that and think: "Hmm, we're doing that a different way" and ours is...Two prongs really. They're doing it a different way and it's not working, and so they look at these and say: "Well possibly we need to change our tack as a way of dealing with the [Enabler_1]." On the other hand they might be...They might have a system that is working fairly well, but they want to better it. They might look at that and think: "Well, we definitely don't want to move in that direction. So what we've got is not perfect, but we'd better stick with it, and tweak it in a different direction from what is indicated here." (Contact_3, End User_1)

Once again, the interviewee highlights the closeness in relationship between the transfer of knowledge (in this instance, procedural knowledge) and the opportunity for the actors within the technological innovation process to learn from the knowledge that is transferred to them.

4.3.1.3 Knowledge Storage and Maintenance

Very few of the interviewees comment to any extent on the storage and maintenance of knowledge within their organisations as it relates to the technological innovation process. Although both the technology providers and end users store implicit and tacit declarative, conditional and procedural knowledge relating to development and application of technological innovations (see Sections 4.2.2.3 and 4.2.3.3), this is not identified to any extent by the interviewees. As can be seen in the previous two sections however, this may be due in part to the perspectives of the technology providers that it is only when knowledge is shared with other organisations that it presents a potential threat, and as such the storage of knowledge within organisations is not viewed as a critical factor within the innovation process itself.

As stated in the previous section, one interviewee from a provider organisation does note the use of the project application forms generated by the enabling organisation as a formal method of codifying, storing and transferring declarative knowledge to end user organisations, and the subsequent use of these forms by the end users in identifying areas in which more declarative, procedural and causal knowledge may be required:

"Operators that had received the form had some additional questions and just phoned me direct because they knew me." (Contact_11, Provider_3)

Additionally, as stated in sections 4.2.1 and 4.2.2, a number of interviewees (notably from the technology provider organisations) suggest that it is not necessarily the explicit knowledge of technologies (transferred by the enabling organisation to end users and technology providers through their lists of ongoing and completed projects) that pose a threat to the confidentiality of new technologies. Rather, the transfer of declarative knowledge relating to the technologies through face-to-face discussions and presentations by the enabling organisation to end users present opportunities for end users and potential competitors to acquire additional explicit knowledge.

However, the understandably protectionist attitude of the technology providers towards the transfer of knowledge relating to the development and application of technological innovations does not appear to extend to the same degree to the end users. One interviewee from an end user organisation comments on the storage and subsequent transfer of knowledge relating the application of a new technology developed by Provider_2, and the willingness of the end user organisation to share this knowledge with other potential beneficiaries of the technology:

"I could have filled three books with the amount of technical stuff we did, but we're not going to provide that to everybody. I can provide my comments, because they're not confidential, but the data quite often is, and that's part of the problem we ran into with that whole technology story, because so many people weren't willing to share technical details, and so because they're not willing to share anything, we tried to share something. If you remember we talked about a study that we eventually let [Provider_2] give to anybody who was

interested. That information really can't be published on a public site or anything like that. That information we said could be given out, but really only to those people who were focussed in on that opportunity, not just for everybody. But most people would say not to anybody." (Contact_7, End User_5)

Again, the interviewee highlights both the issues of confidentiality surrounding the transfer of procedural and declarative knowledge by end user organisations, and the appropriateness of the methods used to share that knowledge. Additionally, the interviewee goes on to highlight the importance and perceived value relating to the temporality of the knowledge associated with a specific technology:

"On the other hand, once a project has gone ahead and been finished, those people move on, and things happen and the focus moves elsewhere or the technology is evolving within their own company and it's really not appropriate to share that with anybody anymore, and who's going to go back to the original situation." (Contact_7, End User_5)

From the above statement, there appears to be a perception that little value is associated with the historical knowledge associated with the development of a technological innovation, and as such the interviewee suggests that although there may be no issues concerning the confidentiality of such knowledge there may be no reason to transfer it to other end users, and as such little reason to store it.

4.3.1.4 Knowledge Creation

Despite the relative lack of comments from interviewees relating to the storage and maintenance of knowledge relating to the technological innovation process, a number of the interviewees comment on the process of knowledge creation as well as the factors which may accelerate or impede the creation of new knowledge in form of new technologies. Specifically, one interviewee from a technology provider notes that while many of the providers themselves are the originators of new technological knowledge, they are heavily reliant on the financial support of the potential end users:

"Well, I was at a decommissioning seminar recently. There is a point which I raised which is that most good ideas come from small/medium enterprises (SMEs), and I'm just talking on my side, on the decommissioning side, so it's a big risk for companies like us to continue investing without support from the operators." (Contact_13, Provider_5)

In addition to the issue of securing funding in order to develop new technologies, the same interviewee notes the difficulty in securing timescales for the application of newly created technologies by the end users:

"One of the draw backs for the operators, and I know the operators work through this [Enabler_1] thing but I'm not quite sure what their strategy is right at this moment in time, maybe it will be clearer at the board meeting is they have some reluctance, if they are in a tender stage, to be seen to be aiding companies develop technology, they keep going on about: "We are looking for more remote for the generic risk, more remote technologies, we need somebody to come up with the good ideas." We come up with the ideas, there's maybe £500,000, a million pound investment and then we find that we build a really clever tool, which can do wonderful things and you are targeting a specific decommissioning scenario, and you find: "Ooh, what a surprise, it's slipped again and we're not doing it until 2009 now." It was mooted for 2007 but because of this, somebody has bought the assets, they are milking more out of it, what do you do with your investment? How do you get your return? So that is a big issue. It's a problem." (Contact_13, Provider_5)

However, another interviewee from a technology provider also comments on the value of Enabler_1 in helping to secure funding from the end users in the development of new technologies:

"I quite liked the way that [Enabler_1] operated before because before they basically talked to companies and said: "What have you got?" Then we would say: "We've got this idea." Then they would go back to the operators and say: "This guy has got some good ideas but they'll need some funding to develop these ideas." Which I thought was good but now I'm not sure what they are trying to do. If they can come up with an idea and they can get funding for people like us then I'll back them to the hilt." (Contact_13, Provider_5)

As an additional route to market and exposure to end users, Enabler_1 is clearly seen by the technology providers as being most beneficial to smaller organisations, which are often reliant on end user organisations providing financial support, not necessarily required by larger organisations as can be seen from the following statement from Contact_11:

"The big service companies like [Provider_8] or whoever, if they want to develop something and they have a good business plan they will just do it and if it costs a few million, or

whatever, it's not a problem. All the new technologies tend to come from small companies. Boffin types of people come up with great solutions." (Contact_11, Provider_3)

Although the technology providers can be seen to be focussed more on the supporting mechanisms underpinning the creation of knowledge, an interviewee from an end user organisation reflects on the actual process of generating new ideas though personal interactions:

"The other thing that struck me was there was one story where they were talking about how they had come up with the idea, and it came up from someone's comment in a conversation. That someone had said: "Such and such has been working on this." or: "Have you talked to so and so? They've been working on something"...And it was another company they talked to, who already had the solution that they were looking for, and the two of them got together and came to a "oh we can work together and actually come up with something." That was quite powerful for me." (Contact_3, End User_1)

The interviewee acknowledges the relationship between knowledge transfer and knowledge creation, and specifically the role of the transfer of declarative knowledge relating both to the technologies and the organisations which have developed them.

4.3.1.5 Knowledge Application and Exploitation

Closely related to the knowledge creation process, the technological innovation process is reliant on the application of the procedural and declarative knowledge of the technology providers and the application of conditional knowledge by the end users (see Section 4.2.3.5). One interviewee from a technology provider notes the difficulty in securing financial support from the end users to turn ideas into technologies which they may subsequently use:

"Well I think so because it is their responsibility to remove or decommission the structures in the most environmentally friendly way. OK there is some degradation going on where they can leave so much in providing it doesn't interfere with the fishing. But they can't say that we would like contractors, or specialist contractors to come up with some clever ideas and we've just to fund it and hope we get jam tomorrow, well it's very difficult. So where we are in a catch 22 is we can end up saying: "Well, we know we can develop this tool and we've got it on the drawing board but we need you to give us a contract or a letter of some intent that you are likely to use us." And they'll turn round and say: "We can't do that because we were

coming out to an invitation to tender and how do we know it will work?" So, we then say: "Well, give us some money, we'll tell you what we've developed, we'll show you it working but you have to fund some of this to demonstrate it will work and then we can get into a bidding situation where you might use it or even consider as a potential preferred contractor."" (Contact_13, Provider_5)

In relation to this perspective, one interviewee comments on the role of the enabling organisation in acting to secure these relationships:

"I know, what do you know. You've got to rank things against...It sounds pretty good, but I've got another ten things I've got to look at, so I'll get back to you. So I think that came across in the fact, yeah, I realise there is an issue out there about the SMEs bringing their things through and therefore there's an issue about the [Enabler_1], but I don't know a better way of doing it. It's just something you've got to be aware of, and I think it's something as an oil company that if we say: "We're interested", we have to get back to people very quickly and say: "Yes, we are going to fund this" so that at least they know we're on board rather than saying: "Yes, I've had ten companies say they're interested, it's six months later, and ten companies are still out there saying to me we might be interested in funding it." I think that to me, that it is confirmed that this is an issue that the [Enabler_1] have, and we need to do something about it, because it does reflect badly on them and from the person trying to get their technology brought to market, you know we might as a company be saying you need to use the [Enabler_1] because we've got funding we can put through the [Enabler_1], and they're basically saying: "No, I don't want to use the [Enabler_1] because I know it's going to take me twelve months before we'll actually get to product. What I actually want is [End User_1] to sign up now, I want [End User_4] to sign up now, I want [End User_11] to sign up now, and if I get three of you then fine, we'll go and do it." And we're saying: 'Well no, you've got to go through the [Enabler_1] to do it. As a route of getting things in to us." (Contact_3, End User_1)

Although the technology providers are seen as key sources of declarative knowledge for the end users, the timescales involved in using the enabling organisation as a route to market for the development of technologies, and their subsequent application by the end users can be seen to adversely affect the innovation process itself. As stated in Section 4.2.1.2, the perceived threat to smaller technology providers by organisations who have access to funding can also be seen to affect the development of new technologies, and consequently their application by end user organisations:

“One of the things I would say - there's a few of the smaller companies are a bit miffed that the likes of [Provider_8] and [Provider_9] are actually in the [Enabler_1] and are looking for support as well, because of two things. They’re well established and they don't need it. If something is going to fly, then they will back it. And two, it actually gives them an insight into what other ideas are coming up from small competitors. And because they've got so much clout, they can say: “That's a good idea. Let's see if we can find another way of doing that, then we'll pinch it.” So there's been quite a lot of kick-back on that from some of the smaller companies, so I'm not too sure if that's something we need to challenge. I know I've probably challenged it before, and you get the same old story: Their technology might need support if it is prohibitively expensive or a completely different change of direction, but I'm not too sure that it was the initial intent of [Enabler_1]to have these big players in there, because it becomes a virtual monopoly.” [Contact_6, End User_4]

Despite the problems associated with the use of the enabling organisation, another interviewee notes that the critical issue of the engagement between the providers and the enabling organisation is the strategic level at which it engages with the end users themselves:

“I think that is a challenge, yes we all have our strategic themes that we need to fit with, so something that is on the side of that, then you could get support for it and I'm sure other companies have other things as to who is going to pay for it and who's budget does it come out of. Different companies have different ways of funding it and that can take time to physically make it's way though the system. I'm sure it is frustrating for the developers and the [Enabler_1] but that's just the way it is. It's a means for small companies getting in to the major operators to try and get funding rather than them knock on all the doors in the company to try and find the right department that might well fund their development. At least coming through Enabler_1, you are coming in at a fairly high level into the company and it filters down internally rather than you coming in at the bottom knocking on various doors. It’s a good system, but it’s a slow system.” (Contact_3, End User_1)

Clearly two factors can be seen to affect the application of declarative knowledge by the technology providers. As has been stated earlier within this chapter, the timescales involved in developing not only the technologies themselves, but the relationships between the different actors directly affect the ability of the technology providers to apply their declarative knowledge in the production of new technologies. In addition, the lack of financial support by the end users also acts as a significant disincentive for providers to develop innovative new technologies.

4.3.1.6 Knowledge Valuation and Measurement

The financing of technological developments can be seen to be a theme which affects all the knowledge-based processes identified within this research. In addition, the views of both the technology providers and end users in relation to the potential threat to the providers in the form of exposing their technologies to competitors can be seen to be a critical factor in the development process. It is interesting to note that despite the significance of this issue, none of the interviewees reflecting on the narratives commented on how knowledge as valued intellectual property is protected by their organisations.

However, from the previous sections it can be seen that the application of processes formalising the relationships between the technology providers and end users by the enabling organisation may be viewed as an attempt to protect the intellectual property of the technology providers, and reduce their financial exposure.

4.3.2 Narrative System: Stored Knowledge

Following on from the interviewees' reflections on the role of knowledge within the technological innovation process following their use of the narrative system, the interviewees were asked to discuss the system itself. The purpose of this was to determine the extent to which the narrative system addressed second part of the sixth research question: Are the actors within the technological innovation process influenced by exposure to the explicit knowledge of other actors, and if so how can this knowledge be codified and transferred?

This section relates to the content of the system (i.e. the explicit knowledge stored within the system) and specifically examines issues surrounding the ability of the users to understand both the content of the system and its intended purpose, the scope of the system, the value of the system in exposing the actors to the explicit knowledge of others, and the anonymity of the content of the system.

4.3.2.1 Comprehension

Considering the perspectives of other potential users of the system, Contact_13 questions the comprehensibility of the stories themselves as written versions of oral narratives:

"... from reading some of mine, it was easy for me to read because I said it. Whether it's easy for someone else to comprehend...It may be long winded, I don't know, and did they understand what I was trying to say and the objective? Rather than say: "Oh this is very interesting," would they want to say: "I want to look into this further, where can I get this?" I don't know." (Contact_13, Provider_5)

Similarly, Contact_14 feels that additional editorial input into the narratives themselves would improve their readability, and additionally help to make them more succinct:

"I must admit when I read the transcript of what I said, I thought surely I don't speak like that do I? It was so literal. I would have preferred if it was more edited to be honest, because it just showed how much I rambled on. That bit, I must admit I cringed when I read it.'" (Contact_14, Provider_6)

In addition to challenging the comprehensiveness of the stories, the same interviewee goes on to identify the broad categories which he feels would have made the content of the system more useful:

"What was the objective? Was it trialled? Was it successful? And this is what it can do. More cold, hard facts because when people are looking at that they say: "Oh I've had this problem, this could be my solution." Maybe it was a little bit too long, because people get bored if it goes on and on. It's nice if you are given the opportunity to read extracts. Maybe in your extracts you have covered that, I don't know. My one is quite condensed but comprehensive." (Contact_13, Provider_5)

Related to the two comments presented above by Contact_13, the representative from End User_1 suggests why the users with a technical background may be more inclined to want the narratives themselves presented in a more factual way, as well as their own desire to write material according to specific highly-structured guidelines:

"The reports that we do, tend to be very structured. Very much cold, hard facts as to what was the reason you did this, what were the inputs to it, what was the decision process you went through, what were the outcomes, and then how was it implemented and what were the results So, its a very structured piece. Then if you get into the transfer of knowledge where you are writing for example an SPE paper, then you basically are given a format that says: "If you want to have your paper accepted it's got to be written like this." So because of that, you tend to write in a particular way." (Contact_3, End User_1)

Contact_3 goes on to propose that although different to the format which many of the potential users of the narrative system may be used to, the content of the system provided an additional 'friendly' element due to the method by which the data was collected. However, this in turn can be seen to have a potential impact on the accuracy of the narratives, despite having been approved by the interviewees themselves:

"So the homely version is actually quite nice because it is somebody talking. The difficulty with it is that sometimes you can interpret what they have said incorrectly because you are going from a recording, and therefore if someone has an accent or pronounces things in a particular way you can pick a word up incorrectly, so that is one of the weaknesses of it...But the homely type nature of it is a friendly way of having somebody talk to you." (Contact_3, End User_1)

The conversion of oral to written narratives may thus present the users of the system with issues affecting the comprehension of the narratives themselves. However, the format of the narratives themselves (although unfamiliar to a number of the users) can be seen to provide a more informal method of knowledge transfer.

4.3.2.2 Scope

The representative from the enabling organisation proposes that while the narrative components which act to structure the data were fit for purpose, it was the format of the information presented within those components which requires additional elements beyond the narratives themselves:

"I think some of the headings you already have are fine, you know it's maybe just how the information is presented under them, in whatever format, whether it's bullet-pointed or statistical or graphical or whatever...I think you probably need both things actually. So I think

the narrative let's you get into the head of the person who's written it a bit more, so they explain in detail their perspective, their story, so that's useful. But then, taking a more analytical approach to it I guess, you know comparing their story with other people's stories, and is there indeed any common things emerging? Or is there anything unique within them that's different?" (Contact_1, Enabler_1)

The interviewee suggests a need for a form of analysis of the data in order to separate the narrative from the scientific knowledge (Lyotard, 1984). The same interviewee goes on to elaborate further:

"I'd say I found it easy to use. I think that in terms of how for example Enabler_1 could use it, I think it needs perhaps more...Along the lines of some sort of summarising of some kind, so you could actually take, what are the messages out if it, because at the minute it's just the narratives. It's actually extracting what the key points are, because even though you can do comparisons between different narratives from different people, it's difficult to necessarily do a comparison from that looking at it. You know, what are the common factors either blocking things, or good things, or things that could be changed. What were frustrations, what were good points?" (Contact_1, Enabler_1)

The perspectives of the end users however, can be seen to be rather different. Whereas the data from the representatives from both the technology providers and the enabling organisation can be seen to emphasise a need for more technically focussed and processed material within the system, the data from the end users suggests that the real value of the system is in helping its users to develop an understanding of the innovation process and the various interactions of the players, rather than an understanding of the technologies themselves. One of the interviewees suggests that it is the specific focus of the players on the technologies themselves which acts to drive the demand for more technically-based material:

"Well, technology guys always like that, but it's maybe the philosophy you want to get over, rather than how to implement this stuff, because that's what Enabler_1 is about. How to get from A to B and then into the market?" (Contact_6, End User_4)

Contact_7 provides a similar view, but suggests that while information relating to the technologies themselves would have been valuable within the system, gaining access to that material would have been a challenge due to the commercially sensitive nature of the material:

"I could have filled three books with the amount of technical stuff we did, but we're not going to provide that to everybody. I can provide my comments, because they're not confidential, but the data quite often is, and that's part of the problem we ran into with that whole technology story, because so many people weren't willing to share technical details." (Contact_7, End User_5)

The data from this interviewee suggests that the use of the Internet for sharing confidential and commercially sensitive material may be inappropriate:

"It seems to me the system is more about the process itself and people's experiences of trying to get to market, and I think there's a value in that last bit. The other bit, the technical information, sure there's a value in it, but you're not going to get it...If a person can get connected with another person one on one they talk to each other. Let's say it's two end users now, myself and another oil company representative get together and we share an interest in a project, and I can learn from his and he can learn from mine. I'm going to give him that hard data and he's going to give me his potential data, and we're going to swap that easily. It doesn't hit the world, it doesn't hit the public, it doesn't hit all the things, and we trust each other to keep it confidential. So I think that's a better way to connect people. Connect the individuals who have common interests first, don't just throw the data out on the Internet or wherever else people can find it." (Contact_7, End User_5)

Despite the lack of technical information contained within the system, the same interviewee acknowledges that the value of the content does not necessarily relate to the impact of the use of the technologies, but more the experiences of the players within the innovation process:

"I think it was good that you just captured some anecdotes to give people confidence that there are some people who really gained from the process. But I don't think you can prove to them in a structured way, a detailed way what they got from it. You're never going to see money or barrels saved discussed in the open. That's not going to happen." (Contact_7, End User_5)

This perspective is also echoed by a representative from one of the technology providers:

"I don't think this research is really based on that, it is more on the relationship between the developers and Enabler_1, rather than the actual technology. So from that point of view I think you have probably got the message across. I would like to see more detail on the

technology but then I don't think it was what this research was about. So from that point of view, the message you were trying to get across, you did." (Contact_11, Provider_3)

Although several users can be seen to desire more formal technical content (in the form of pre-digested or analysed material) within the system itself, the interviewees appear to understand the purpose of the system and its potential value both to current and future users. The interviewees appear to understand the purpose of both scientific and narrative knowledge, and identify functions for both forms of knowledge. As stated above, where knowledge in a narrative form provides opportunities to acquire understanding of the motivations, beliefs and desires of the actors, it does not provide such a useful opportunity to develop an understanding of the technologies themselves, or how they may be applied.

4.3.2.3 Value

In line with the views presented in the previous section, from the perspective of the enabling organisation Contact_1 suggests that the narratives provide an opportunity to develop a better understanding of the various issues affecting both the ability of the technology providers to develop new technologies, and the potential uptake of those technologies by the end user organisations:

"It was interesting reading the stories from the point of view that it gave different people's perspectives of the technology development process, and as you'd expect very much from their own perspective of what they were trying to achieve from it, and where the difficulties lay and what they did to try and get around them. You'd have a vague idea of say for example what an end user's needs might be, and what some of the issues were, but by reading it you got more of an in-depth understanding of those issues." (Contact_1, Enabler_1)

Contact_1 thus echoes the postmodernist perspective of Lyotard (1984) by suggesting the importance of using the website as a method of acquiring knowledge relating to the different perspectives of each individual. This is further emphasised in section 5.3 which examines the interviewee's perspectives on the relationships between the actors, and how knowledge is shared between them.

As part of the research methodology, the interviewees were sent copies of the transcriptions of their interviews, and given the opportunity to remove any commercially sensitive material. However, the effect of this process on the readability (and concomitant value) of the stories contained within the system is highlighted in the following quote from Contact_3:

"The things that I took out were a couple of things that I had referred to which were confidential and I couldn't do that, so I had to delete them. So it works well. The difficult thing is because you use the terms endorser or developer or whatever, and when you keep replacing those words in the text, in order to protect or give it anonymity, it can make it difficult, because when you're in conversation you use those names all the time and when it's written, it's bang, bang, bang, bang, bang." (Contact_3, End User_1)

The interviewees were relatively evenly divided on the issue of the format of the content of the system. A number of interviewees (principally consisting of representatives from the end users) can clearly be seen to derive a value from the use of personal narratives, as opposed to more factual, technically-based material relating to the technologies themselves which was requested by the enabling organisation and the technology providers. Notably, the interviewee from the enabling organisation reflects on the potential value of the system as a learning tool for potential future players within the innovation process as mediated by Enabler_1:

"I think it would be useful. But I guess maybe more in terms of, if you could provide something more on the analytical side of it. So what are the key messages from it? What are the key learnings from it? So it could almost be like an aid to somebody that hadn't attempted it before, so what are the lessons and what approaches could you take to make it easier to achieve? And an understanding of what are the difficulties that might arise, but also what are the benefits you get from doing it as well." (Contact_1, Enabler_1)

Although there can be seen to be a range of opinions regarding the content of the system, there are clearly potential benefits to future players within the innovation process who may use the system as a tool to acquire procedural ('know how') knowledge. However it is interesting to note the division in perspectives between the interviewees in their views of the value of scientific versus narrative knowledge (Lyotard, 1984). While a number of the interviewees can be seen to understand the value of knowledge in a narrative form, this does not appear to be a replacement to, or a substitute for, scientific knowledge. The two forms appear to be beneficial in differing ways to the interviewees. While the declarative knowledge in the form of scientific knowledge may be perceived as lacking within the system content, the causal and procedural knowledge embedded within the narratives provides an opportunity to understand the motivations and decisions of the actors within the innovation process.

4.3.2.4 Anonymity

In relation to the content of the system itself, a number of the interviewees highlight the use of anonymous data (critically in relation to the names of companies who had participated in the research), the names of projects or technologies which those organisations had developed or were seeking to support, and also the names of individuals pertinent to the study. Although the majority of the participants in the first part of the main study insisted on having their stories made anonymous due to commercial sensitivities or indeed due to technological development projects which were unsuccessful for whatever reason, a number of the users of the narrative system feel that this was in fact somewhat frustrating from a users' perspective:

"...the only thing that I thought was that it was quite difficult to know what the subject matters were. You had to start a story before you really knew what it was about. Because I think it is a bit of a...In terms of confidentiality, I felt that I didn't want to give too much away because even your competitors are looking at it, and they're thinking: "Hmm, so that's what they're doing, is it?" Or you didn't want to give too much away because you know...I take it some of the stories are there because things didn't go as planned particularly, or there were lessons learned to be had. I'm not sure if people would really want to divulge that, because it almost shows a weakness in their ability to do a certain thing." (Contact_14, Provider_6)

This issue can also be seen to relate closely to concerns on the part of the technology providers relating to the acquisition and transfer of declarative knowledge by/to their competitors. However, given the specific nature of the technologies being developed, one interviewee does acknowledge that despite the use of codes for each project, individual and organisation, it is still possible to identify the various players:

"I didn't know who all the people were. I would have found that quite interesting but you could work it out if you wanted to, but that's ok." (Contact_11, Provider_3)

It is interesting to note that while the technology providers are clearly concerned about providing potential competitors with commercially sensitive information, there was a perception that the narratives themselves could be used as a source of declarative knowledge in its own right.

4.3.3 Narrative System: Knowledge Structure and Interface

In addition to the content of the system, the interviewees were also asked to discuss their experiences in relation to the structure of the narrative system. Principally, these experiences relate to performing three key activities supported by the system: reading stories, writings stories and comparing stories. The interviewees were also asked to comment on the system's user interface.

In relation to the interface, two of the interviewees comment that this is an element of the system which could have been improved upon. Contact_3 for example suggests that the system is not welcoming to potential users:

"I think I made some comment that the user interface could be a bit more friendly, in the sense of it being a bit more inviting. It's very bland at the moment when you go in." (Contact_3, End User_1)

Another interviewee from one of the technology providers feels that the use of drop down lists to select the various narratives was confusing as after a specific narrative had been selected, the drop-down list would default to the organisation at the top of the list rather than the organisation which had been selected:

"The only thing I noticed...What confused me initially then I worked it out, was when you use the drop down menu. For instance it would give you the options of enabler, provider or whatever, and you picked one, say it was Enabler_4, It would bring up Enabler_4 to read right enough but that pull down menu would always say Enabler_1 or whatever. Now I know that it had the title below it, but I kept looking at that [the dropdown menu]. So I'm not sure how that would work. You're right enough, it does give the title below it in big bold letters, but I just kept looking back to the dropdown menu. It was just an instinctive thing I did." (Contact_14, Provider_6)

Although the interviewee does acknowledge the use of the titles of the narratives in navigating the system, the use of drop-down menus could clearly be improved to aid navigation.

4.3.3.1 Comparing Narratives

Although the interviewees generally agree that the ability to compare the stories from different players was a useful feature of the system, the usability of this feature is seen by several interviewees to be somewhat compromised due in most part to the way in which the narratives are presented on screen. If the users selected a large number of narratives to compare, then they are presented with a large amount of information. As a result of this, several users find the material difficult to absorb:

"I agree with what you've written. I mean it's quite difficult to follow this company, this company, and this company, but you can read along the lines." (Contact_6, End User_4)

Similarly, the representative from Enabler_1 states:

"I think, as I say, even at that level it's still difficult to do comparisons across the way between them." (Contact_1, Enabler_1)

Clearly then the volume of material which is presented to the users is thought to be too much, and again emphasises the desire for pre-digested material, rather than material in a purely narrative form. As a result of this, one of the interviewees suggests a search feature within the comparison feature of the system in order to enabler users to locate relevant material. However, the interviewee does also note that the abstracts of the narratives may provide summarised information:

"A keyword search, I guess just for the comparison part of it maybe, so you can compare like with like, or something similar. Because you had to really read through all the stories to see if you could find the ones that you thought were relevant. But I guess maybe the abstracts would give you that if they're written in a certain way. I'm not sure." (Contact_14, Provider_6)

Similarly in relation to the ability of the users to compare stories, Contact_1 feels that there may be a desire on the part of the users not to read the complete narratives or large amounts of information, but *"...to quickly assimilate from it what are the common things or unique things."* (Contact_1, Enabler_1)

Contact_14 further emphasises this point which can be seen to be a reflection on the amount of time needed by the users to read the various narratives:

“I did have a play about within the system, but I didn't really go into too much detail regarding reading other people's stories I must admit. But I guess I could see if you had the time to go through the stories, then there would be things that you'd see that would be common to ourselves or whatever.” (Contact_14, Provider_6)

One interviewee from an end user organisation does however explicitly emphasise the value of this feature of the system, and in particular the ability of the users to select from the various elements of the narratives themselves:

“The key for me...The winning for me was the piece where you are comparing the various stories. So you could take the complicating event, and you picked three or four stories to look at, that for me was a more powerful piece, because it was saving you...You didn't have to look through the whole story. You could look at the stories that were in and say: “Right, the thing I'm interested in is what caused the problems, therefore, I'll have a look at the complicating event.” So then, let's say you pick four of the stories and they show you what the complicating events are, and you can see if there are similarities or whether they were just totally different. Then you can say, well the ones that were similar, then you can start to burrow down into the rest of the documentation that gives you the feeling for, the projects were totally different, but they still had very similar complicating events which caused a problem.” (Contact_3, End User_1)

The use of the narrative/SSM template to structure the stories, and thus the ability of the users to compare elements of the narratives can be seen to be been particularly useful to this interviewee, but notably not to them all. Indeed the interviewee emphasises that it is the stories separated into these various elements which provides the main opportunity to acquire knowledge, as opposed to the narratives in their entirety:

“For me, the breaking down into those elements, so you can then compare the pieces across, to see where the differences were, and then you can pick those differences out as things to follow up on. That was the main learning, rather than looking at the whole story. Which was in some places, because you are using a transcript, it's monotonous and rambling. You don't realise when you are talking that you are rambling a bit, because you're having a conversation aren't you? But when it’s actually verbatim, then you read through it and you can think: “Ah, did I really say that?”” (Contact_3, End User_1)

The interviewee suggests then that the method of gathering the narratives further compounds the need for the stories to be divided into their component parts, and that it is the components of the narratives themselves that are more comprehensible.

4.3.3.2 Writing Narratives

Although none of the interviewees added any new stories to the system (beyond those which had been added from the transcripts of their first interviews), several of the interviewees do comment on the potential ability to add new narratives to the system. Contact_6 also suggests that it is unlikely that any new stories would be added by users from the end users organisations:

"Well, I always resist having to write anything for anything, because it takes some time, and you get no thanks for it at the end of the day, but if it was something that Enabler_1 filled in, that would be fine. That could be something that they could do off their own bat. But I don't think you'll find any of the operators willing to volunteer their time for you to fill it in." (Contact_6, End User_4)

However, one of the interviewees from another end user organisation does clearly examine the capacity of the system to include new stories. In this instance the resistance from the user in relation to writing a new story for inclusion within the system appears to be related to the system interface, rather than unwillingness to their volunteer time:

"The key for me, and I thought I could see when I went in initially and started looking at the form for putting the data in, thinking that this looks pretty complicated because you are asking for it to be split. Initially you think you have to put the whole thing in twice. You have to put it in in pieces and then write a text. It's only when you then move on to start looking at the completed stories that are in, you realise that it's one story that you have actually split into the various pieces that you want to break it down into." (Contact_3, End User_1)

Conversely, when asked to consider the ease of which new stories could be added, Contact_1 suggests that the system interface is less of an issue:

"Yes, I think so, because you had a bit of a title and then a bit of a descriptor to go along with it to say what it was about, so yeah, I think so." (Contact_1, Enabler_1)

It is interesting to note, given the concerns of several of the interviewees relating to confidentiality, that none of the interviewees comment on this in relation to their willingness or otherwise to add material to the system.

4.3.3.3 Reading Narratives

Lastly in relation to the structure of the system, the interviewees were asked to comment on their ability to read the narratives contained within the system. Contact_6 suggested that while the system contained a relatively large amount of material, it was possible to navigate through it effectively:

"I didn't realise how long it would take to read through all the material. But it was easy enough to hit the buttons and find my way about. It was flexible actually. You could hit the mark very quickly." (Contact_6, End User_4)

Indeed although the interviewee does not comment on the specific nature of the flexibility of the system, he does appear to suggest that it is the overall flexibility of the system which enables users to navigate effectively:

"I thought what you were trying to do in the system was flexible. You could see what you wanted to see quickly." (Contact_6, End User_4)

Contact_11 expands on this view to suggest that the interface in fact aids in his ability to locate and read the narratives of other players:

"I thought it was clear. I read some of the other stories you had in there and it seemed very similar to what I had said myself." (Contact_11, Provider_3)

Returning to the issue of the volume of material contained within the narratives as well as the format of the narratives themselves, Contact_14 highlights the individual nature of each of the stories, which can clearly be seen to be influenced by the various 'storytellers':

"I was wondering whether that would be determined by the style of writing. You know, you might have had to scroll down three or four paragraphs to find the bit you wanted, whereas someone else's story might have hit that point right at the start. Perhaps if the narratives were

limited to so many words maybe, so people would try to condense what they were saying, so you'd get the information more quickly." (Contact_14, Provider_6)

Access to the original data in audio form was also identified by one interviewee as a potentially beneficial addition to the system. It is suggested that not only does this avoid potential errors during the editing process, but also helps to convey a more emotional perspective on the stories themselves:

"I think it would be useful to have sound files embedded in the website so that people to listen to the stories, providing that people were happy for that to happen. It would give more of a flavour to, were they speaking quite passionately about it, or was this just a piece of work that they did, you know, pretty boring, not really very excited about it but they did it and were successful, or they weren't successful and that's why they weren't happy about talking about it. Yes, I suppose that would give more of a flavour for the excitement that might be involved in a research and development project. I suppose that would also help you if there were parts of the written prose that you couldn't quite follow, you could say: "Right, I'll listen to that part of the sound file to see whether I can understand it when the person is speaking to me, and it's just a misinterpretation of the words." That would cover for that rather than having to rely on somebody else's interpretation of maybe what should be written there." (Contact_3, End User_1)

Again, the conversion process from oral to written narratives appears to present issues relating to the comprehension by the users, and the interviewee identifies a potentially valid extension to the existing system.

4.4 Summary

This chapter has presented the findings of the research. Section 4.2 presented the findings based on the data gathered from the project participants using narrative interviews. It presented the perspectives of each group of actors identified within the technological innovation process as they relate to the knowledge-based processes used within the analytical template discussed in the previous chapter, as well as the forms and types of knowledge associated with each of these processes. Specifically, these findings have presented the actors' perspectives relating to what the knowledge-based processes and forms and types of knowledge (identified from the literature) present within the technological innovation process are, how these manifest themselves within the technological innovation process, and also their significance within this process.

Following a similar structure, Section 4.3 provided the findings as they relate to both the knowledge-based processes and the narrative system following the interviewees' engagement with the system in order to determine how the actors are influenced by exposure to the explicit knowledge of other actors, and how the narrative system may be used to store, structure and transfer that explicit knowledge to the actors. The next chapter presents the discussion of these findings.

CHAPTER FIVE: DISCUSSION

‘There is nothing more difficult to plan, more doubtful of success, more dangerous to manage than the creation of a new system. The innovator has the enmity of all who profit by the preservation of the old system and only lukewarm defenders by those who would gain by the new system.’ (Niccolò Macchiavelli)

5.1 Introduction

This chapter discusses the findings derived from the analysis of both the narrative and semi-structured interviews as they relate to the actors, the knowledge-based processes and forms of types of knowledge presented in Sections 4.2 and 4.3.1, and the system designed to store the narratives presented in Sections 4.3.2 and 4.3.3. The chapter brings together the discussions of Parts 1 and 2 of the findings in order to address research question 6: Are the actors within the technological innovation process influenced by exposure to the explicit knowledge of other actors, and if so how can this knowledge be codified and transferred?

The chapter presents the discussions relating to each of the processes (contributing to objective 4: To identify the knowledge-based processes which exist within the process of technological innovation, develop generalisable typologies and characterisations of those processes, determine the extent to which they manifest themselves and their significance within the technological innovation process) in relation to the interactions between these groups (contributing to the achievement of objective 2: To identify actors within the technological innovation within the UK upstream oil and gas industry, develop generalisable typologies and characterisations of those actors and their roles, and to determine the nature and significance of their knowledge-based interactions.), and the content of those interactions (contributing to objective 5: To identify the forms and types of knowledge present within the process of technological innovation, develop generalisable typologies and characterisations of those forms and types of knowledge, determine the extent to which they manifest themselves and their significance within the technological innovation process).

Sections 5.2 to 5.7 present the discussions relating to the actors, the knowledge-based processes and the forms and types of knowledge, and further contribute to addressing the following research questions:

Research Question 2: Who are the actors within the technological innovation process in the UK upstream oil and gas industry, what are their roles, and what is the nature of their knowledge-based interactions?

Research Question 4: What knowledge-based processes occur within the technological innovation process, how do they manifest themselves, and what is their significance within this process?

Research Question 5: What forms and types of knowledge are utilised within the technological innovation process, how do they manifest themselves, and what is their significance within this process?

Section 5.8 presents the discussion as it relates to the use of the narrative system in providing a vehicle to store and transfer explicit knowledge and again further contributes to addressing the following research question:

Research Question 6: Are the actors within the technological innovation process influenced by exposure to the explicit knowledge of other actors, and if so how can this knowledge be codified and transferred?

Key findings for the research are identified and discussed in Sections 5.2 to 5.8, and revisited in the summary of the chapter provided in Section 5.9 and the next chapter. Although not discussed explicitly within this chapter, the discussion leads to reflection on the philosophical stance (specifically in relation to the validity of narrative knowledge, and the meaning which may be attributed to works from differing perspectives) and will be revisited in Chapter 6.

5.2 Knowledge Acquisition and Learning

The data gathered from the narrative interviews can be seen to support Nickols' (2000) model (presented in Section 2.3), as knowledge can be seen to be acquired by the actors in these three forms: tacit, implicit and explicit. These forms appear to impact on the ways in which the knowledge is acquired by the actors, and additionally the types of knowledge acquired seem to determine the mechanisms of knowledge acquisition.

Critically, the issue relating to the forms of knowledge and the processes by which these forms of knowledge are acquired seem to relate closely to the issues surrounding the difficulties in determining the differences between data, information and knowledge. Central to this debate is the difference (or lack thereof) between explicit knowledge and information identified above. Although this issue has already been raised within the review of the literature within Chapter 2, it is important to raise it within the context of the primary research.

From the data, much of the acquisition of knowledge by the actors appears to be from educational and industrial environments as stated by the technology providers in Section 4.2.2.1, and the end users in Section 4.2.3.1, as well as from each other (see Figure 20 below). It is unhelpful and overly simplistic to assume that knowledge acquired within either of these contexts is in a specific form, and to separate what may be defined as knowledge, information or data. Indeed Stemark (2002) suggests that data, information and knowledge are interwoven and interrelated in 'complicated ways' (2002, p.3).

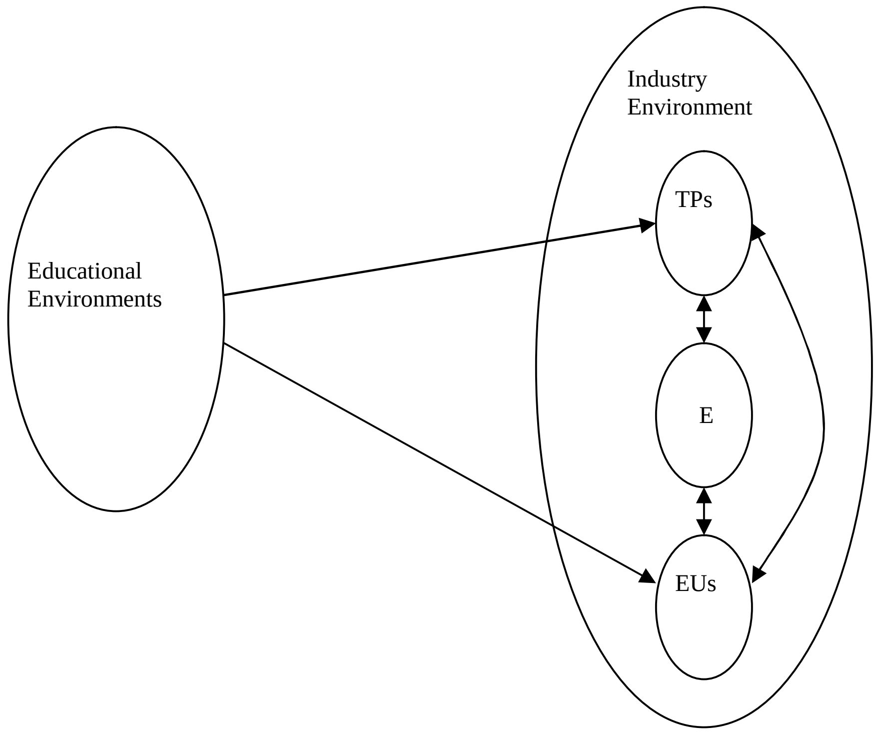

Figure 20: Knowledge Acquisition Sources

Similarly in relation to the forms of knowledge, Pathirage, Amaratunga and Haigh (2007, p.117) state that: 'Since tacit knowledge is linked to the individual, it is very difficult, or even impossible, to articulate. Explicit knowledge, in contrast, is codifiable knowledge inherent in non-human storehouses including organisational manuals, documents and databases. Yet, it is difficult to find two entirely separated dichotomies of tacit and explicit knowledge, instead knowledge can fall within the spectrum of tacit knowledge to explicit knowledge.' However, it is possible to determine from both the primary and secondary data which types of knowledge can broadly be seen to come from which sources.

Al-Hawamdeh states that 'Knowledge in the form of skills and competencies is normally acquired through training and interaction with the environment.' (Al-Hawamdeh, 2003, p.19). Following on from this perspective, Wong and Radcliffe (2000) argue that knowledge capabilities can be seen to be tacit, unlike documented sources which can be regarded as explicit knowledge. Similarly, Abell and Oxbrow (2001) provide this definition: '...knowledge is what people know; information is how they communicate it.' (2001, p.73). This can be seen to be closely related to the model proposed by Van Beveren (2002) in figure 21:

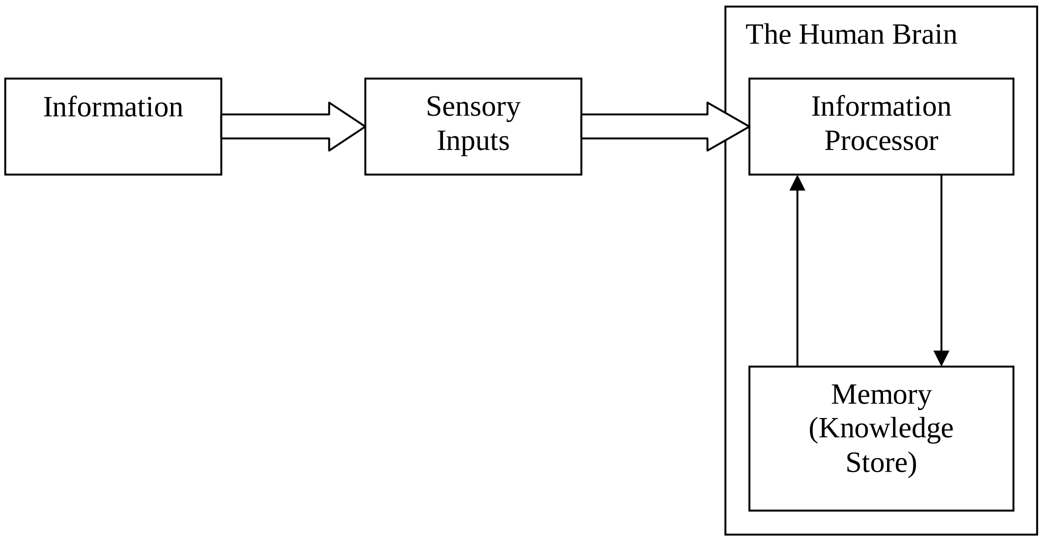

Figure 21: Model of information acquisition and knowledge creation [Source: Derived from Van Beveren (2002, p.20)]

As such, the actors can be seen to be acquiring (or have already acquired) a large degree of knowledge (principally declarative and procedural knowledge) through their formal education which they bring with them when they enter the industry, and also both formally and informally through their training and experience within the industry itself. Jantunen (2005, p.337) states: 'Learning tends to be a path-dependent activity in the sense that new knowledge acquisition is largely determined by the existing knowledge base, on both the individual and the organizational level.'

In addition to the highly tacit knowledge acquired by the actors through their environment, training and education, the actors can also be seen to acquire different types of knowledge from each other as well as other players within the industry. Although much of the ongoing knowledge acquisition by each group of actors can be seen to occur informally and indeed serendipitously (see sections 4.2.2.1 and 4.2.3.1), the enabling organisation can be seen to act as a more formalised route for ongoing knowledge acquisition for both the technology providers and the end user organisations. Specifically, the technology providers can be seen to acquire declarative knowledge from the enabling organisation in relation to the technology needs of the end users, whereas the end users acquire declarative knowledge relating to who the potential providers of new technologies are and indeed what those technologies are.

In the context of the enabling organisation, the declarative ('know what' and 'know who') and procedural knowledge ('know how') of the technology providers is acquired through the proposal process. This knowledge is then subsequently shared within the enabling organisation as part of the proposal evaluation, and in an on-going sense with the potential end users of the various technologies.

This in effect identifies two distinct types of knowledge acquisition within the technological innovation process: the acquisition of tacit knowledge through learning and experience; and the acquisition of explicit knowledge through acquiring information. Al-Hawamdeh (2003) states (in direct contradiction to Lundvall and Johnson, 1994) that both 'know how' and 'know who' types of knowledge may be expressed and articulated. This can be seen to be particularly true in relation to the role of the enabling organisation in providing a mechanism by which the end users may acquire the declarative and procedural knowledge of the technology providers, and is a key finding of the research which is discussed further in Section 6.2.1.

This finding can be seen to be highly significant in several ways. Firstly, although Al-Hawamdeh (2003) suggests that both procedural and declarative knowledge may be acquired, this is discussed in a purely theoretical basis. In contrast this research provides a practice-based context (the technological innovation process within the UK upstream oil and gas industry) within which these forms of knowledge can be seen to be explicitly expressed and articulated, and thus presents primary research to support this theoretical perspective.

Furthermore, while prior research into the innovation process highlights different forms of knowledge (e.g. Jensen et al, 2007; Faulkner, 1993; Balazs, 1996; Rothwell, 1994) there have been no previous studies which have explicitly linked the types of knowledge to the process of knowledge acquisition, and explicitly relates the roles of the different actors to these knowledge types. Again, this research builds on and extends understanding of the role of knowledge acquisition within the innovation process generally by identifying the types of knowledge acquired by actors, the significance of these knowledge types within the innovation process, and more specifically within the context of the technological innovation process in the UK upstream oil and gas industry.

All the technology providers who participated in this research were SMEs. Specifically in relation to SMEs, Gray (2006, p.348) states that ‘there are generally two main areas where the effective management of these various types of knowledge is crucial to growth or survival:
(1) the functional areas of the business, which relate to the people in the firm; and
(2) strategy and the need to remain competitive, or at least viable, which relate to the firm itself as an organisation.’

From the data, the technology providers appear to acknowledge that the acquisition of tacit procedural (‘know how’) knowledge in the form of new individuals employed by the organisation impacts on the ability of the organisation not only to provide the end users with new innovative technologies, but also to allow the organisation to identify potential routes to market through the use of implicit conditional (‘know where’ and ‘know when’ knowledge).

Alavi and Leidner (2001) identify only one type of conditional knowledge: know when. However this research clearly shows an additional type of conditional knowledge present in the technological innovation process: know where. Specifically, this type of knowledge is acquired by technology providers from both the enabling organisation and the end users and is used to identify potential locations for the application of their technologies. The identification of a new type of conditional knowledge is a key finding for the research, and is significant in two ways. Firstly, it extends the theory relating to knowledge types by writers such as Lundvall and Johnson, 1994, and Alavi and Leidner, 2001). Secondly, it again contributes to understanding of the role of knowledge within technological innovation process in the UK upstream oil and gas industry.

In addition to the acquisition of tacit and implicit knowledge, the technology providers also acknowledge the value of acquiring explicit knowledge through attending industry events such as those provided by Enabler_1. These events then provide the technology providers with routes to acquiring an understanding of the declarative knowledge needs or gaps of the end users, and subsequently aid the technology providers in determining if their procedural knowledge (in the form of expertise) and/or their declarative knowledge (in the form of existing technologies) could be used to close those gaps.

The initial acquisition of the technology providers' explicit declarative and procedural knowledge (of technological innovations) by the end users can be seen to use the enabling organisation as a formalised route through which the end users can acquire new knowledge. This knowledge of the technology providers can initially be seen to be highly formalised and explicit in the form of completed and ongoing projects lists. However once the enabling organisation has established a link between a technology provider and an end user; both players can be seen to acquire knowledge through personal interactions.

The declarative knowledge of the technology providers is contextualised by the end users themselves who act to determine the potential applicability of the technologies within different technical and/or geographical environments through the application of their own declarative and conditional knowledge. Due to their nature, the end user organisations can be seen to have large knowledge-bases, and the individuals responsible for sourcing technological innovations have detailed understanding of the potential application of novel technologies as well as these environments.

The absorptive capacities of the end user organisations, which Zahra and George (2002, p.186) characterise as 'a dynamic capability pertaining to knowledge creation and utilization that enhance a firm's ability to gain and sustain a competitive advantage' is then dependent on their existing knowledge base (Cohen and Levinthal, 1990). The importance of both the acquisition of knowledge (and arguably) the absorptive capacity of these organisations should not be underestimated. As Jantunen (2005, p.339) states: 'Accumulated prior knowledge enhances the ability to assimilate knowledge related to the existing knowledge base. In that sense, absorptive capacity may be a potential source of competitive advantage. The firm that has a large knowledge base is well equipped to understand new scientific knowledge and its commercial applicability, for example.'

As with the end user organisations, the importance for the technology providers not only to acquire but absorb knowledge is critical. Easterby-Smith et al (2008, p.484) further highlights the importance of absorptive capacity: 'On one hand it draws attention to the need to appreciate and acquire knowledge from the external environment, especially from acquisitions and other inter-organizational relations; on the other it focuses on learning from past experience and current actions, and the internal processes for translating this into useful action.' Both of these elements can be seen to be identified from the narratives provided by the technology providers, and is again a key finding for the research (see Section 6.2.1).

Significantly, the interviewees appear to consider the absorptive capacity (Zahara and George, 2002) of other players within the technological innovation process, most notably the consideration of the technology providers (Zahara and George, 2002). This in itself is a significant finding in that it reveals not only a broader consideration of the process of knowledge acquisition by the actors, but also highlights the importance to the technology providers of developing their own understanding of the processes and routes by which both the end users and providers acquire knowledge.

While previous studies have identified the importance of absorptive capacity in the innovation process (e.g. Cohen & Levinthal, 1990; Zahra and George, 2002; Liao et al, 2007) these again have not emphasised the different roles adopted by the actors within the process or how these roles affect and influence their abortive capacity. Critically, this research builds on work by others and extends understanding of the significance of absorptive capacity not only to knowledge acquisition, but also to the technological innovation process and its importance to the relationships which exist between the players within the UK upstream oil and gas industry.

However, the acquisition of the declarative or procedural knowledge of the technology providers is determined not only by the absorptive capacity of both the individuals and the organisations themselves but also by the geographical and technical areas of focus identified by the technology providers. As these areas of focus change over time, then so too must the technologies developed by the technology providers if they are to address these areas. This in turn emphasises the need for the technology providers to acquire and absorb the declarative knowledge relating to those areas which they acquire from both the enabling organisation and the end users directly.

Despite these issues, there was no acknowledgement from any of the interviewees from any of the groups that the acquisition of tacit and/or implicit knowledge happened within a formalised learning context within their own organisations. Indeed much of the acquisition of declarative knowledge by the end users relating to the technology providers can be seen to be serendipitous (see Sections 4.2.2.1 and 4.2.3.1), and this is a key finding for the research which is discussed further in Section 6.2.1.

The serendipitous identification of relevant technologies or capabilities on the part of the end users, or the identification of potential end users or funding sources, appears from the data to occur with some degree of regularity. Indeed, serendipity appears to be a valuable route for both the acquisition of new knowledge and the opportunity it presents to technology providers to present their declarative and procedural knowledge and to the end users to present opportunities for new technologies.

The data shows that for the technology providers and end users, participation and exposure within the industry context (though approaches such as attending and presenting at industry events) can increase the number of serendipitous encounters which may in turn lead to technological innovations. The importance of serendipity is another key finding of this research and is discussed further in Section 6.2.1.

Specifically, the end users recognise that much of their ongoing declarative ('know what') and procedural ('know how') knowledge acquisition as it relates to the technology providers happens serendipitously, and this again echoes the views of the end users as presented in Section 4.2.3. The role of serendipity remains an almost completely unexplored area in relation to both the innovation process, and indeed knowledge acquisition. This research clearly shows its importance in relation to the acquisition of relevant declarative knowledge within the technological innovation process. Specifically in the context of the UK upstream oil and gas industry, the serendipitous identification of potential users of technologies by technology providers and the identification of viable technologies by end users can be seen to be a vital consideration for actors within the innovation process.

Like the data from the first set of interviews, the data from the second set of interviews also emphasises the importance of the informal and serendipitous nature of knowledge acquisition by both the technology providers and the end users from sources outside their organisations. However, unlike the first set of interviews where the interviewees reflect on how they themselves acquire knowledge serendipitously, the data from the second set of interviews shows that following their engagement with the narrative system, the interviewees tend to reflect less on the methods by which knowledge is acquired at a personal or organisational level within their organisations, or indeed the sources or types of knowledge acquired.

Instead, the technology providers use the narrative system as a mechanism by which to examine their own organisations as sources of declarative ('know what') knowledge for other organisations which may be acquired serendipitously and formally (through engagement with the enabling organisation) both by the end user organisations and in addition, their competitors. The technology providers tend to reflect to a much greater extent on the commercial risks involved in using the enabling organisation as a potential route to market.

This is valuable within a context of relatively little radical change such as the UK upstream oil and gas industry, however in business contexts which are prone to radical change, a large existing knowledge stock may not be so beneficial as Jantunen (2005) warns: ‘The existing knowledge base also filters incoming signals, and hence new information is always interpreted in the light of earlier experiences within the framework of existing concepts and understanding...Signals that do not directly fit in existing cognitive frameworks will easily be filtered out.’

The technology providers view the acquisition of declarative knowledge by the enabling organisation as both an opportunity and a threat to the development of a technological innovation. Although the enabling organisation is not acknowledged as a threat in its own right, its ability to acquire and subsequently transfer knowledge to both the technology providers as well as the end users is recognised as a significant risk to the technology providers. This risk is also further enhanced through the time taken for a technology provider to engage with the enabling organisation. Thus the greater length of time this process takes, the greater the opportunity for the acquisition of declarative knowledge by competing technology providers. The potential impact of this acknowledgement by the technology providers is highly significant in that it could potentially affect the number of new technologies coming to market using the enabling organisation as a vehicle, and thus undermine the role of the enabling organisation itself.

Additionally as with the first set of interviews, the interviewees focus on the acquisition of knowledge in the form of information either directly from the technology providers or end users or through the enabling organisation, rather than the acquisition of knowledge through learning (Al-Hawamdeh, 2003). In line with the first interviews the technology providers acknowledge the enabling organisation in the critical role it plays both as a source of explicit declarative (‘know what’) knowledge relating to the technological needs of the end user organisations, and also in acting as a source of guidance (procedural ‘know how’ knowledge) for both the technology providers and end users in their engagement within the innovation process (Azzone and Maccarone, 1997).

An additional and related significant difference between the first and second interviews is in relation to the perspectives of both the technology providers and the end users with regard to the appreciation of potential conflicts of interest between the technology providers and service companies whose employees are board members of the enabling organisation. As the service companies both acquire declarative knowledge in the form of technological innovations from the technology providers (and as such are both end users and technology providers in their own right), the data shows that following their engagement with the narrative system, the technology providers have an increased awareness of how their declarative knowledge may be acquired by competitors through the enabling organisation, and the potential detrimental effect this may have on the development of a new technology.

Although the data from the second set of interviews shows that the end users are aware of the potential threat to the development of new technologies by the technology providers through their engagement with the enabling organisation, it also highlights their comparative comfort with the acquisition of their own declarative ('know what') and procedural ('know how') knowledge by other end users in the form of information (Van Beveren, 2002). Critically, the end users highlight the importance of trust as an influencing factor in both the transfer and subsequent acquisition of knowledge (Davenport and Prusak, 2000), an issue which is not identified by the technology providers and can clearly be seen to relate to the concerns on the part of the technology providers regarding the acquisition of their declarative knowledge by their competitors.

5.3 Knowledge Transfer and Dissemination

As can be seen from the previous section (and indeed the review of the literature), the process of knowledge transfer is closely related to the process of knowledge acquisition. Indeed, Van Beveren (2002, p.20) presents the following model in which the transfer of knowledge is presented as a process of 'outputting' knowledge as opposed to the input of knowledge through knowledge acquisition as seen in Figure 22.

Of all the knowledge-based processes identified and examined within this research, the transfer of knowledge between the different groups of actors can be seen to have the most significance in the development and subsequent application of technological innovations. Critically, all the groups of actors within the study can be seen to reflect on the role of the enabling organisation as a knowledge conduit, and consider both the benefits as well as the drawbacks of their involvement within the innovation process. Knowledge transfer and its relationship to the process of knowledge acquisition within the innovation process, and the interactions which take place between the different groups of actors, is critical within the context of the technological innovation process: 'In the knowledge-based economy, innovation is driven by the interaction of producers and users in the exchange of both codified and tacit knowledge; this interactive model has replaced the traditional linear model of innovation' (OECD, 1996, p.7).

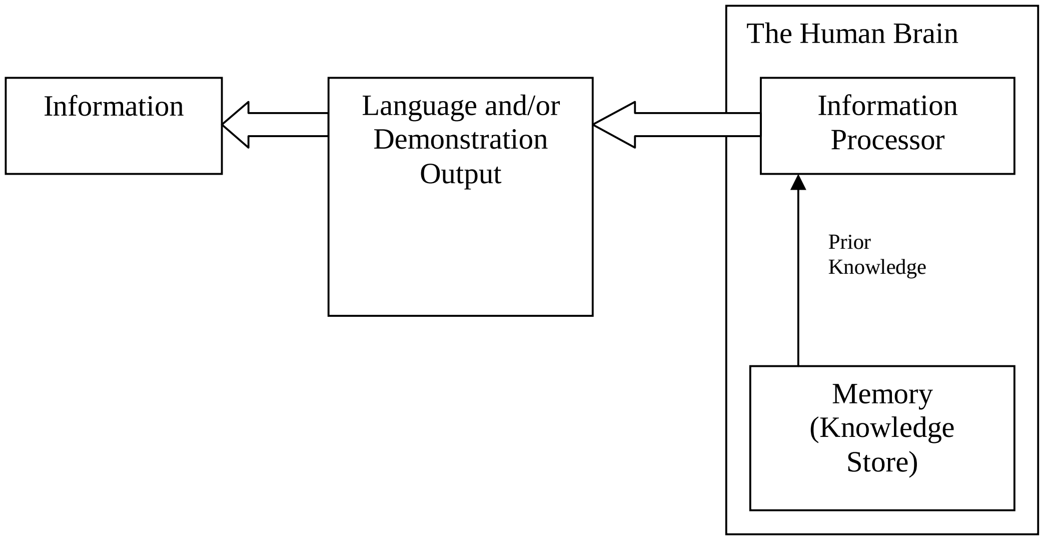

Figure 22: Model of Knowledge Transfer to Information for Externalization [Source: Derived from Van Beveren (2002, p.20)]

From the previous section, the enabling organisation can clearly be seen to acquire procedural and declarative knowledge relating to the capabilities and technologies of the technology providers which is then transferred in an explicit form to the end users. Similarly, the enabling organisation acquires and transfers the declarative ('know what') knowledge needs of the end users to the technology providers.

The enabling organisation has a number of functions in relation to the transfer of knowledge within the innovation process. Firstly, it acts as a 'knowledge conduit' through which declarative and procedural knowledge passes between the technology providers and the end users. However, the enabling organisation also acts to facilitate knowledge transfer within groups of actors. Using the following figure as an example of typical interactions, the enabling organisation acts as a knowledge conduit acquiring knowledge from both technology providers and end users, and transferring it as required. However, the enabling organisation also facilitates the transfer of knowledge between individual technology providers and end users (TP_1 to EU_3), and in addition acts to facilitate the interactions between individual groups of technology providers (TP_4 and TP_5) and groups of end users (EU_4-6).

As discussed within the review of the literature, Azzone and Maccarone (1997) state that enabling organisations act to provide five support functions to aid the process of innovation: information; training; consultancy; qualification; and integration. In relation to these functions, this research build on prior work by identifying that the enabling organisation provides a critical role within the innovation process through supporting the integration of the technology providers and the end users.

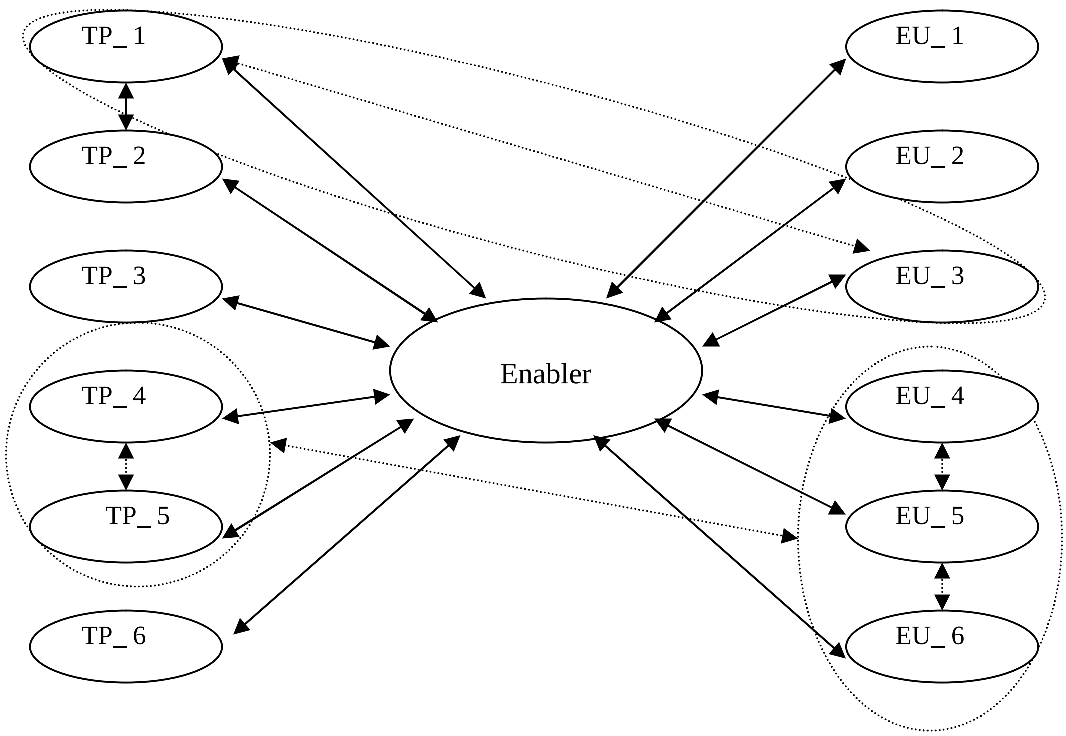

Figure 23: The Enabling Organisation as Knowledge Conduit

As with the second form of knowledge acquisition (i.e. that form of knowledge acquisition which is not learning-dependent), the transfer of knowledge can be seen to be reliant on both tacit and explicit knowledge, however it can be seen from the data that tacit knowledge (by its very nature) must be made into an explicit form before it can be transferred. Al-Hawamdeh (2003, p.18) states that: 'Knowledge embodied in documents does not necessarily translate into useful and usable knowledge unless it is read, digested, manipulated and communicated from one person to another. In other words, knowledge can only reside in the minds of people; once it is outside the human mind it is information.'

As well as transferring explicit declarative and procedural knowledge to the end users through the enabling organisation, the technology providers also try to share their knowledge with the end users directly through marketing their technologies. Hanvanich, Droge and Calantone (2003) suggest that marketing knowledge is embedded within three marketing processes: supply chain management, product development management and customer relationship management, however they go on to suggest that practitioners face difficulties in defining both what knowledge and more specifically marketing knowledge is. The ability of the technology providers to transfer knowledge of their capabilities ('know how') and technologies ('know what') successfully is dependent on an additional form of declarative knowledge: 'know who'. Critically, the enabling organisation can be seen to aid the technology providers to transfer their knowledge to the end users if it fits with their technology themes (see Section 4.2.3.2).

The enabling organisation thus acts as a filter for knowledge transfer between the groups of actors by not only deciding what to share and in what form, but also by deciding what knowledge not to transfer. In respect of the end user organisations, the enabling organisation may decide not to transfer explicit knowledge of capabilities and technologies if they do not fit with the technology themes of the end users. However this again is dependent on the enabling organisation's understanding of what these are. Equally, the enabling organisation may not transfer declarative knowledge relating to the commercial sensitivities of the technology providers (see Section 4.2.1.2).

The representatives of the enabling organisation can be seen to make conscious decisions regarding not only the methods by which knowledge may be transferred, but also which knowledge should and should not be transferred. This issue is a significant finding of the research and is again discussed in Section 6.2.1. This research again builds on prior research which identifies barriers to the transfer of knowledge (e.g. Davenport and Prusak, 2000, Pawar and Sharifi, 2002). However prior work in this area has focussed on the identification of cultural and technological barriers to knowledge transfer, and has not focussed on this dichotomy of enabling organisations acting as barriers to the transfer of knowledge. Thus, this research extends understanding both of actors as barriers to knowledge transfer, and understanding of the ways in which enabling organisations may actually impede the innovation process itself. Understanding these factors is critical to actors within the technological innovation process if they are to engage with enabling organisations.

The reasons as to why the representative from the enabling organisation may be privy to this kind of sensitive knowledge can be seen to relate to one of the critical barriers of knowledge transfer: trust. The literature review identifies lack of trust as one of the key cultural barriers to knowledge transfer between individuals. In this instance, trust (between the technology providers and the representative from the enabling organisation in particular) can be seen to act as a catalyst for the transfer of declarative knowledge from the technology providers to the end users, resulting in a situation where the enabling organisation must decide what knowledge to transfer to the end user organisations (Davenport and Prusak, 2000).

Intra-organisational knowledge transfer can also be seen to be an important element within the development of a new technology, and this can be seen to be particularly evident within the end users. For example, Contact_5 recognises the need for both the need for facilitation in bringing groups of individuals together from distinct but complimentary groups within the organisation as well as the need to develop a common language to help to overcome knowledge transfer barriers (see Section 4.2.3.2). Specifically in relation to the innovation process, Amidon emphasises the need for an explicit innovation process which draws together competencies across the organisation: ‘Creation of an innovation strategy may be the bonding initiative that creates the common language, capitalizes on distinctive competencies, and fuses collective knowledge into a shared purpose. However, few organisations have an explicit innovation process – never mind a designated senior executive responsible for oversight of that process.’ (1997, p.65).

In the case of this research, each of the end user organisations can be seen to have senior management support for the acquisition of new technologies (as evidenced by the interviewees themselves). However the data clearly indicates that this in itself is not enough to support the knowledge transfer process within the end user organisations. The same interviewee thus acknowledges a significant issue raised by Amidon (1997, p.47) in relation to, what she refers to as ‘the management system’: ‘In some respects, it is the realisation that there are economic, behavioural, and technological dimension to all the work done in an organisation. This broadening of the responsibilities of a function – together with the mandate to develop a collective vision – has established the foundation of a common language and the need for capitalizing on distinctive competencies for competitive advantage.’

Like knowledge acquisition (following on from Sections 4.2.3.2 and 4.3.1.2), an additional important factor which can clearly be seen to influence the transfer of knowledge (particularly between the technology providers and end users) is serendipity. Davenport and Prusak (2000) identify a number of strategies for increasing the likelihood of serendipitous knowledge transfer within organisations, most of which can broadly be seen to relate to creating both spaces and times available to individuals. However in relation to inter-organisational knowledge transfer, this can be seen to be more challenging. Nonaka and Konno (1998, p.40) for example propose that the Japanese concept of ‘Ba’ may act to support personal and group interactions, and may be thought of as ‘a shared space for emerging relationships’. They suggest that this space may be a virtual environment, thus potentially helping to address one of the barriers to inter-organisational knowledge transfer.

The data reveals that following their engagement with the narratives much of the focus of the interviewees' reflection on the innovation process, and their own understanding of that process, relates to the transfer of different types of knowledge between the different groups of actors and the relationships existing between those groups which act to facilitate or adversely affect the transfer of knowledge (Dixon, 2000).

In accordance with the data gathered from the first set of interviews, the end users specifically seem to acknowledge and appreciate the value of personal networks as enabling mechanisms for the innovation process (see Section 4.2.3.2). Not only are these networks critical to the overall success of a technology development project by providing a mechanism for both the technology providers and the end users to share declarative and procedural knowledge, but they also act to help create personal relationships between individuals (Pawar and Sharifi, 2002). This issue closely relates to the perspectives presented by the end users in relation to the importance of trust in the acquisition of knowledge, and again further emphasises the close relationships between the transfer and acquisition of knowledge in the form of information.

Although the relationships between the technology providers and the end users as mediated by the enabling organisation can be seen to be part of a formalised process of technology development, the data can be seen to show that the three different groups of actors recognise the important role played by personal relationships between individuals involved in the process (Wright and Taylor, 2003). This correlates with the views of the actors presented prior to their use of the narrative system (see section 4.3.2), and as such can be seen to act to reinforce their existing perspectives as presented in the previous chapter.

In the first set of interviews, the technology providers can be seen to consider the enabling organisation as a knowledge transfer conduit from which the end users could acquire knowledge relating to the capabilities and technologies offered by the technology providers. Additionally the enabling organisation is perceived to transfer declarative knowledge to the technology providers relating to the technological requirements of the end users. The second interviews show the interviewees reflect on the enabling organisation as a knowledge conduit knowledge which may be used by their competitors to acquire knowledge of their own technologies, and this can be seen to be a significant finding for the research.

Like the key finding identified above relating to the enabling organisation as a barrier to knowledge transfer, this finding is particularly relevant to actors involved in the technological innovation process. This finding suggests a detrimental effect of the role of the enabling organisation on the technological innovation process in its role as a knowledge conduit.

Prior research in this area falls into two categories. Either this has tended to identify the broad groups of actors within the innovation process and their interactions in a generic sense (e.g. Hall, Mytelka & Oyeyinka, 2005; Lu & Etzkowitz, 2008), or they have examined the processes of knowledge transfer in relation to technological innovation, but have not identified the content of those transfers in relation to the types of knowledge (e.g. Szulanski, 1996), or indeed the specific roles of the actors involved. This research makes explicit not only the forms and types of knowledge present within the transfer of knowledge, but furthermore highlights the specific roles of the actors in relation to these forms and types. Furthermore, it identifies the specific role of enabling organisations as not only conduits for the transfer of knowledge but also impediments to the process, and indeed as agents for the inappropriate transfer of declarative knowledge.

Again, the data reinforces the relationship between the processes of knowledge acquisition and transfer, and as such may be seen as two ends of a distinct process of knowledge exchange in which one actor externalised their tacit or implicit knowledge and then transfers that explicit knowledge to another whom in the process acquires new knowledge. This can be seen to relate closely to the models presented by Van Beveren (2002) in Sections 5.2.

However, what Van Beveren's (2002) models do not consider is the role of third parties within the knowledge acquisition and transfer process, and the concomitant effect this may have on the successful transfer of knowledge. Importantly, the actors appear to have (to differing degrees) an understanding of the knowledge of other actors: in effect, declarative ('know what') knowledge of the knowledge of others. In relation to this research, this perspective can be seen to impact on all the players involved in the technological innovation process in different ways. From the data gathered from the first set of interviews it can be seen that in relation to the enabling organisation, it is highly important to have an understanding of the explicit declarative ('know what') knowledge needs of the end user organisations and the abilities of the technology providers to fulfil those needs in the form of both their procedural ('know how') and declarative ('know what') knowledge.

From the perspective of the technology providers, the reliance on the absorptive capacity of a third party, the enabling organisation (Jantunen, 2005), and its ability to represent and transfer their declarative and procedural knowledge presents a significant risk. Although this is mediated to some extent through the transfer of explicit knowledge (codified by the technology providers themselves) in the form of the project proposal process, this importance of serendipitous and informal knowledge transfer provides additional opportunities for both technology providers and end users to acquire knowledge from other routes which are not influenced by the knowledge owners or creators. In effect then, although the enabling organisation acts as a conduit for the transfer of knowledge between the technology providers and the end users, it may also act as a conduit for the transfer of inaccurate knowledge and even as a barrier to knowledge transfer through failing to transfer knowledge (Dixon, 2000).

From the perspective of the end user organisations, this is also a risk as it may prevent their access to technologies or capabilities which may have a beneficial impact on their operations. A critical role then of the enabling organisation is to act as an effective conduit of accurate knowledge between the technology providers and the end users, and between the players within the end user community.

Although the data shows there are clearly other routes of knowledge between the different actors (directly between themselves, and indirectly utilising other enabling organisations), the enabling organisation acts to inform both groups and consequently to ensure that (where appropriate) they have an understanding of the range of knowledge types proffered by each group, and in the case of the technology providers, the declarative knowledge requirements of the end users. In effect then, the enabling organisation aims to reduce the element of serendipity involved in the innovation process within the UK upstream oil and gas industry.

Despite the critical role played by the enabling organisation as a conduit for the transfer and acquisition of knowledge by both the technology providers and the end users, both technology providers and end users identified two critical areas (which were not previously identified in the first set of interviews) in relation to the use of the enabling organisation as a knowledge conduit.

Firstly, as has been noted above, the technology providers explicitly identify their use of the enabling organisation as a potential threat to the development of new technologies. By acting as a conduit of knowledge to both technology providers and end users, the enabling organisation may expose the technologies of the providers to their competitors. This was identified as a concern of the providers not only in terms of their existing technologies, but also their inclination to use Enabler_1 as a potential route to market. As the data shows, this clearly has a significant effect both on the availability of new technologies for the end user organisations, and the ability of the technology providers to gain access to the end users through their engagement with the enabling organisation.

The role of the enabling organisation as a conduit of knowledge between the technology providers and the end users also provides an additional barrier to the transfer of knowledge between these two groups. As an intermediary within the knowledge transfer process, the enabling organisation can be seen to impede the process of technological development through the use of contractual arrangements, and more generally the time taken to formalise the relationships between these two groups. The use of the enabling organisation can be seen to provide an additional level of complexity in the transfer of declarative knowledge from the technology providers to the end users at the initial stages of development. However, changes in the contractual arrangements can also be seen to provide an ongoing barrier to the relationships between the providers and the end users throughout the lifespan of a project.

5.4 Knowledge Storage and Maintenance

Although the storage of knowledge is not a process acknowledged as a core function of an enabling organisation by Azzone and Maccarone (1997), it can be seen to be an implicit element in relation to the transfer of the explicit declarative knowledge of the technology providers to the potential end users. A number of early studies have examined the relationship between the storage of explicit knowledge and innovation (Abbey, 1983; Moorman and Miner; 1997; Tang, 1999). These studies have indicated that the codification of knowledge and its concomitant transformation of that knowledge into an explicit format have generally not affected innovation and, although this was not formally acknowledged by the interviewees, may go some way to explaining why this was not explicitly identified as a critical function of both the enabling organisation in supporting the innovation process, as well as the technology providers themselves.

Before any explicit knowledge can be transferred it must firstly be stored in an explicit form or a tacit form and then subsequently transformed through socialisation or externalisation into tacit knowledge (Nonaka and Takeuchi, 1995). Although the storage of explicit knowledge was generally poorly recognised by all the actors (see sections 4.2.1.3, 4.2.2.3 and 4.2.3.3), the production of the list of ongoing and completed projects by the enabling organisation (including the developers details, the project value, status, and a summary of the technology itself) can be seen to show the enabling organisation as a repository of explicit knowledge. Indeed the enabling organisation can be seen to store different types of explicit knowledge. The enabling organisation stores the explicit declarative ('know what') knowledge of the technology providers' technologies, the explicit declarative knowledge ('know who') in the form of who the technology providers are, and the procedural knowledge ('know how') of their capabilities. As stated in the previous section, this knowledge (which has been acquired from the technology providers) is then subsequently transferred in an explicit form to the end users (see Figure 24 below).

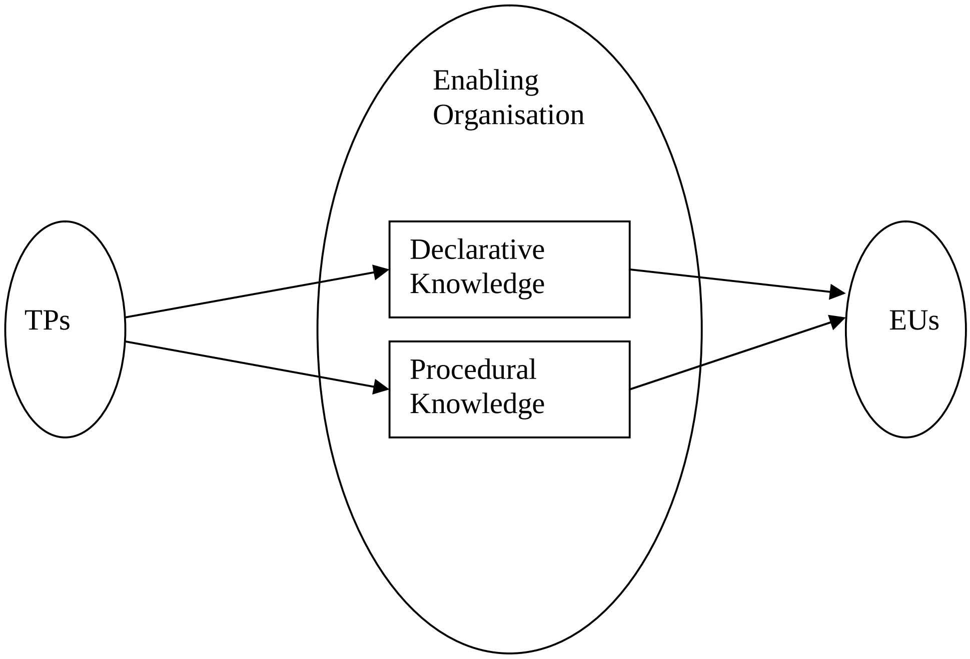

Figure 24: Stored Forms of Explicit Knowledge within the Enabling Organisation

In addition to the explicit knowledge stored within the enabling organisation, the implicit and tacit knowledge of individuals can also be seen to form a significant part of the knowledge-base of the organisation. Indeed the explicit knowledge stored within the organisation can be seen to be a subset of the collective tacit knowledge, and thus supports Polanyi's perspective on the relationship between tacit and explicit knowledge (Polanyi, 1966).

Contact_1, the representative from the enabling organisation, can be seen to have a number of different types of tacit and implicit knowledge types which critically affect the success of the innovation process (Polanyi, 1966). Firstly, he has implicit declarative ('know who') knowledge relating to who the technology providers are. As discussed previously this knowledge may have been obtained either formally through the formal proposal process utilised by the enabling organisation to acquire knowledge of technologies and capabilities, or informally through discussions with other players within the innovation process: providers, enablers and additionally other enablers.

Secondly, he has declarative (‘know who’) type knowledge relating to the end user organisations. This knowledge can be seen to highly formalised as the enabling organisation can in effect be seen to be a ‘members only’ club. Without formal membership of the enabling organisation, end users cannot gain access (using this route) to the technology providers, and subsequently to the technologies which they provide. Related to both of these areas of declarative knowledge is the knowledge of the technologies proffered by the technology providers (‘know what’), and the declarative knowledge of the technology requirements of the end user organisations. Additionally the interviewee has a knowledge of the capabilities of the technology providers (‘know how’) knowledge, and also the applicability of that knowledge within the context of the end user organisations (‘know where’ and ‘know when’) in the form of implicit conditional knowledge. This knowledge can be seen to be maintained and updated by the continuing relationship with the technology providers and the ends users within the context of specific projects (see Figure 25 below), and thus further highlights the relationship between the transfer and storage of implicit knowledge.

Nonaka and Takeuchi (1995) suggest that it is the change of knowledge between its tacit and explicit states that leads to the creation of new knowledge and subsequently to innovation, as Fink and Holden (2007, p.70) suggest: ‘To create new knowledge tacit knowledge has to be made explicit, transferred, combined with other available knowledge, and reconverted (internalized) into new tacit knowledge.’ However it is important to bear in mind that the views of Nonaka and Takeuchi are primarily focussed on the creation of new knowledge within organisations rather than the creation of new knowledge between organisations, and in addition (as Glisby and Holden, 2002) reflect identified elements of organisational behaviours present in Japanese organisations rather than Western organisations.

With regard to the technology providers, the data shows that there was no indication of the explicit knowledge stored within the organisation. However, the technology providers can be seen to acquire and subsequently store tacit and implicit knowledge relating to their own ability to develop new technologies (procedural ‘know how’ knowledge) and the contexts within which those technologies may be applied (conditional knowledge), as well as knowledge of the technologies themselves (declarative ‘know what’ knowledge). As well as these knowledge types, the technology providers also acquire explicit knowledge of the needs of the end user organisation which they acquire through their engagement with the enabling organisation and directly through the end users themselves (see Figure 26 below), and also acquire additional explicit conditional knowledge ('know where' and 'know when') from the end users.

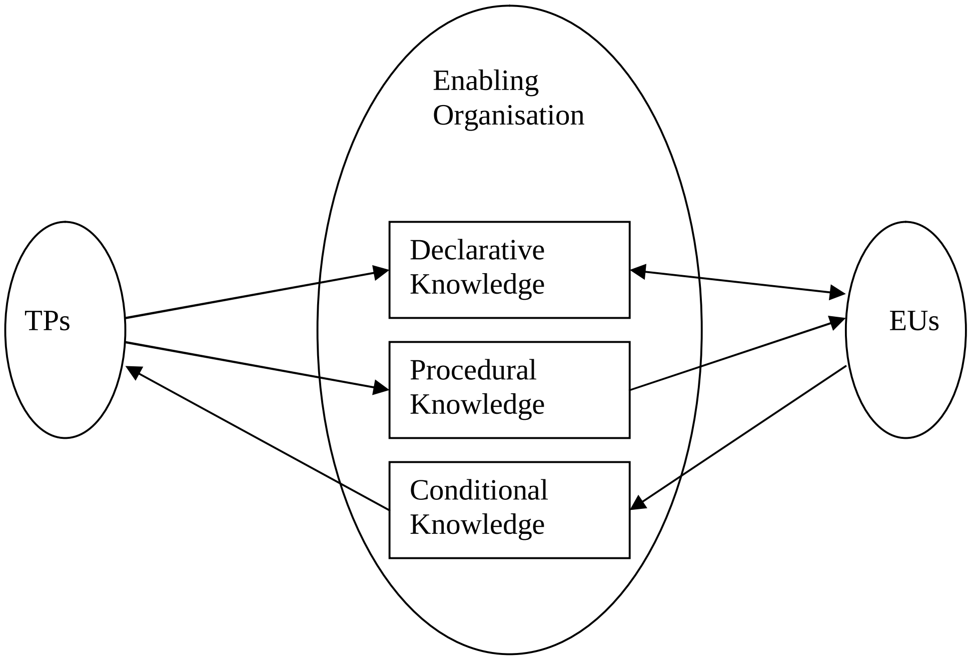

Figure 25: Stored Forms of Implicit Knowledge within the Enabling Organisation

Like the technology providers, there was little acknowledgement of the storage of explicit knowledge relating to the technological innovation process by the end users. Davenport and Prusak state tha: 'The aim of codification is to put organizational knowledge into a form that makes it accessible to those who need it. It literally turns knowledge into a code (though not necessarily a computer code) to make it as organized, explicit, portable, and easy to understand as possible' (2000, p.68). However, Davenport and Prusak go on to emphasise that this codified material does not replace the tacit skills of individuals, but is instead a complement to it. Davenport and Prusak thus suggest that not all knowledge is codifiable, and indeed that not all knowledge should be codified: 'Knowledge in organizations ranges from the complex, accumulated expertise that resides in individuals and is partly or largely inexpressible) to much more structured and explicit content' (2000, p.70).

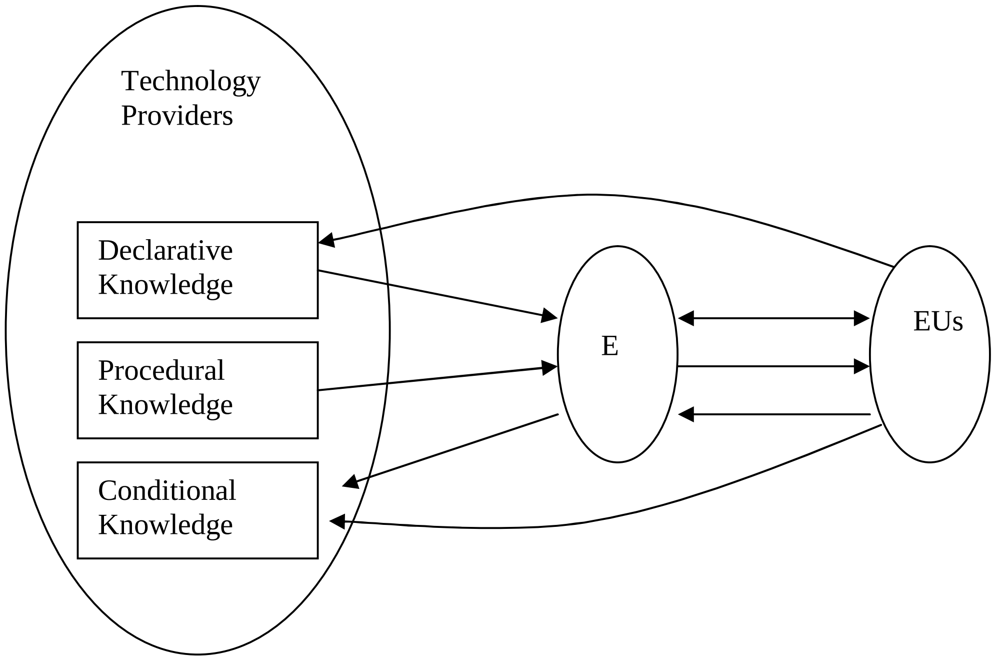

Figure 26: Stored Forms of Knowledge within Technology Providers

This perspective provided by Davenport and Prusak (2000) also helps to explain the lack of stored explicit knowledge by the end user organisations. However in relation to the tacit and implicit knowledge stored by the end users, they can be seen to retain implicit knowledge relating to the technology requirements of their own organisations (declarative 'know what' knowledge), causal knowledge as to why these requirements exist given the different environments within which the organisation operates, and the contexts within which the different technologies may be applied (conditional knowledge). Additionally the end users acquire and store implicit knowledge of the procedural ('know how') knowledge of the technology providers, and declarative knowledge of their technologies ('know what') which they obtain both directly and through the enabling organisation (see Figure 27 below).

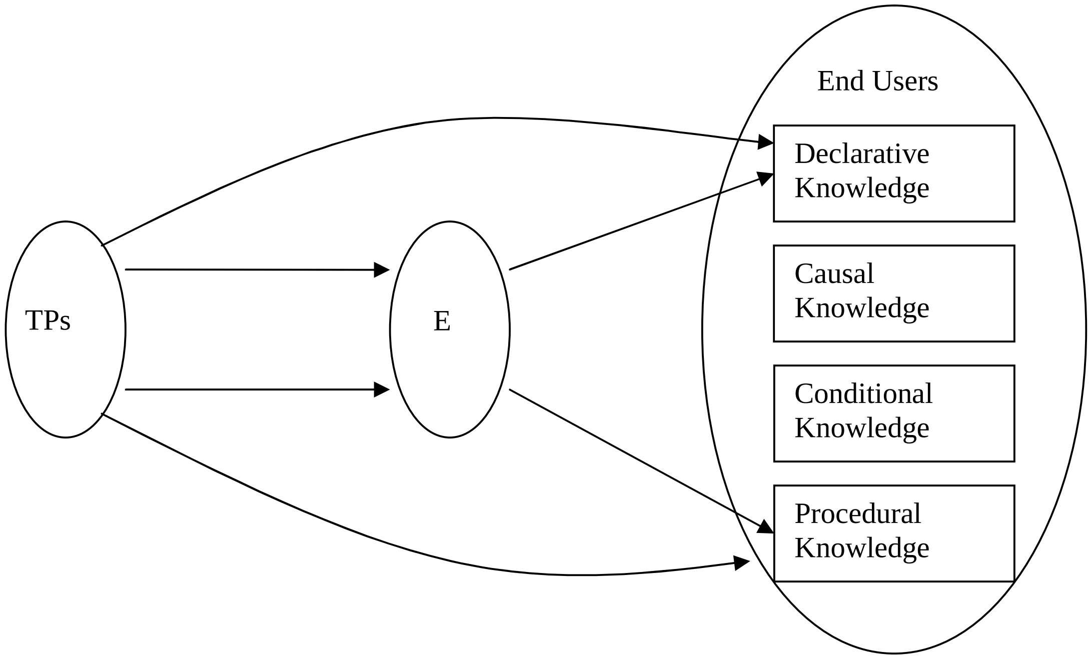

Figure 27: Stored Forms of Knowledge within End Users

The relative lack of explicit knowledge stored by the technology providers, enabling organisation and end users may be a further indication of the large degree of highly tacit knowledge present within the innovation process in the form of technical and subject expertise, which Bender and Fish (2000, p.127) suggest is in effect a form of deeper knowledge developed by an individual. So while different types of knowledge are clearly stored by each group of actors within the innovation process, these are largely tacit and implicit and thus are stored within the individuals themselves rather than in hard copy or electronic forms, and is an additional key finding of this research.

This finding contributes to understanding of the role of knowledge within the technological innovation process, and the importance placed on the different forms of knowledge. This research has shown that while the storage of explicit knowledge by actors involved in the innovation process within the upstream oil and gas industry remains largely overlooked, this does not critically affect the overall effectiveness of the innovation process per se. Implicitly this issue further highlights the importance of the tacit knowledge of the actors within the innovation process. Goh (2005, p.11) suggests that: ‘since the role of knowledge-based assets is directly linked to innovation performance, it also means that a highly systematic and structured approach to managing the processes for creating and capturing it, classifying it and storing it, disseminating and using it for innovation, should be adopted.’ However, this research disproves this perspective within the context of the UK upstream oil and gas industry. This research instead reveals that the critical form of knowledge to the technological innovation process is tacit knowledge, and that the innovation process itself is not signficantly affected by the lack of stored explicit knowledge by any group of actors.

The data shows that there was little reflection by the interviewees on the role of the storage and maintenance of knowledge within the innovation process following their use of the narrative system. The findings of the first part of the research revealed that the declarative knowledge of the technology providers is highly tacit. This factor, along side the concerns of the providers in relation to the acquisition of their declarative knowledge by their competitors, may explain why there was little reference made to the storage of knowledge or the process of converting tacit knowledge into an explicit form. As was stated in section 4.3.3, the storage of knowledge is not considered to be a core knowledge-based activity within the innovation process (Azzone and Maccarone, 1997). However, the storage of knowledge in both tacit and explicit forms provides the basis from which knowledge may be shared, acquired, and (in Nonaka and Takeuchi's view) created.

The data from the second set of interviews does not reveal any new insights on the perspectives of the actors in relation to the methods by which knowledge (in any form) is stored and maintained; however it is interesting to note the reluctance of one of the interviewees in relation to the sharing of codified knowledge. This, along with the willingness of the interviewees to describe and share their own experiences of the technological innovation process as mediated by the narrative system, suggests that the interviewees adopt very different stances in relation to their willingness to codify and subsequently share different types of knowledge. The interviewees (and especially the technology providers) can be seen to be less concerned with the storage and transfer of more 'subjective' knowledge (in the form of personal opinions, experiences, and opinions) and exposing those types of knowledge to their competitors. However, they clearly adopt a more protectionist approach to the storage and subsequent transfer of knowledge in the form of technical information.

This issue can be seen to relate closely to the concerns of the technology providers in the role of the enabling organisation as a conduit of knowledge to their competitors, and their potential resistance to using Enabler_1 as a route to market for new technologies. It does however go some way to explaining the formalisation of the use of procedural knowledge by the enabling organisation to ensure the protection of the intellectual property of the technology providers.

An additional factor worthy of note which relates to the attitudes of the interviewees to subjective knowledge is the perspective on the role and value of historical knowledge relating to technological innovations. Although the technical information and learning acquired by the participants in the development of a new technology (on the part of both the technology providers and the end users) is significant (see section 4.3.1) and may provide the basis for the development of incremental developments, in one instance the interviewee from an end user organisation does not appear to place any potential value on it as a source of knowledge for the future development of technologies due to the rapid pace of development, and indeed the changing strategic technological directions of the end users.

5.5 Knowledge Creation

Within the broad context of the knowledge economy, the creation of new knowledge can be seen to play a pivotal role. Naturally enough, within the innovation process the data clearly shows the group of actors most focussed on this process is the technology providers. Chermin and Nijhof (2005, p.136) state that: ‘Knowledge creation is therefore perceived as one of the major assets of innovative organisations, and innovative organisations are defined by knowledge creation. It seems that innovation and knowledge creation are defined by themselves.’ Despite this, the data from the technology providers can be seen to indicate that there was little formal acknowledgement of the process of creating new knowledge (see section 4.2.2.4).

Hislop (2005, p.157) provides the following valuable perspective on the relationship between innovation and the creation of knowledge: ‘At a common-sense level, innovation is often characterized as being primarily a knowledge-creation process. Thus, from this perspective, whether developing a new product, or transforming an organization’s working practices, innovation is concerned with going beyond the realms of existing knowledge, and developing new knowledge and insights....much organizational innovation is relatively incremental in nature, involving the modification rather than transformation and replacement of existing knowledge.’ In relation to the primary data, Hislop’s perspective suggests that the process of knowledge creation is so embedded within the technological innovation process that the entire process may be viewed as one of knowledge creation, and this may help to explain the lack of acknowledgement of knowledge creation as a distinct activity within the technological innovation process.

However, the data also shows that in most instances the ideas for new technologies have arisen from the interactions between individuals within the technology provider organisations and additionally between personal interactions between the technology providers and the end user organisations (see section 4.2.2.4), showing the importance of both knowledge acquisition and knowledge transfer to knowledge creation. Specifically, these interactions impact on the creation of new knowledge by the technology providers in the following ways. Firstly, while the tacit procedural ('know how') knowledge of the technology providers forms the basis for development of any new technology, it is also reliant on the ongoing acquisition of explicit conditional ('know where' and 'know when') knowledge from the end users and the enabling organisation to help in determining where and when a new technology could be successfully applied (see Section 4.3.1), and in the acquisition of declarative ('know what') knowledge in the form of the technological requirements of the end users.

Bender and Fish (2000, p.125) state that these ongoing relationships between the actors may also be extended to encompass the application of knowledge, and may also help to clarify the complex relationships which exist between data, information and knowledge: 'The knowledge-creating process begins again as the recipient of the data adds meaning to transpose the data into information, then enriches the received information with his or her own personal values and beliefs, thus building his or her individual knowledge by personal application. In this sense, people can transfer data or information, but the knowledge itself has to be created in the head of the individual.'

This can be seen to be particularly true in instances of incremental technology developments by the technology providers (see Section 4.2.2.4), and where the end users themselves have transferred existing technologies from other contexts or industries. Related to this perspective, Chermin and Nijhof argue that: 'On many occasions...retrieving insights from prior learning is important, together with sharing this knowledge in a company, sometimes in the form of new combinations of existing knowledge' (2005, p.136). These perspectives can be seen to echo strongly the concept of combination within Nonaka and Takeuchi's SECI model (1995), where existing explicit bodies of knowledge are combined in order to produce new knowledge.

The enabling organisation acts to facilitate the knowledge creation process of the technology providers by aiding the involvement of the end users in the development process (see Section 4.2.1.2) through transferring knowledge of the end users specific contextual requirements to the technology providers ('know where' and 'know when' conditional knowledge types). The importance of this activity is highlighted by Perez-Bustamante (1999, p.11): 'As it happens with scientific information, to culminate the innovation process it may also be necessary to obtain additional information about the real or potential commercial performance of the product. This information will provide data from the potential customers' likes and dislikes, their needs, the quality levels demanded and information about the products and services provided by competitors as well as the quality they offer. Since market knowledge becomes obsolete more easily than scientific knowledge, the commercial knowledge reservoir may not be updated and thus, potential and real customers may have to be contacted in order to renew it.' Perez-Bustamante (1999, p.11) goes on to emphasise the importance of the enabling organisation in the acquisition of knowledge by the technology providers: 'Thus, the organisation will have to set up links between the innovation chain and the real or potential market. These links will be activated by the customer service department, the commercial and sales force or the technological and market gatekeepers.'

Although the technology providers can be seen to be the creators of new declarative knowledge in the form of new technologies, the end users can be seen to support and guide the knowledge creation process of the technology providers themselves (see Sections 4.2.3.2 and 4.2.3.4). Thus, the transfer of different types of knowledge between the providers and end users can be seen to be a critical element of the knowledge creation process, a contention which is supported by Nonaka and Takeuchi (1995), and more explicitly by Von Krogh, Ichijo and Nonaka (2000). Referring to the support required by organisations in the knowledge creation process as 'knowledge enabling', Von Krogh, Ichijo and Nonaka (2000, p.4) state that 'knowledge enabling includes facilitating relationships and conversations as well as sharing local knowledge across an organization or beyond geographic and cultural borders.'

The importance of this opportunity to understand the needs of the end users by the technology providers, and subsequently their ability to create new knowledge in the form of technologies, is emphasised by Quintas (2005, p.256): 'Whether knowledge is shared or created, at the boundaries between organizations in supply-chain relationships, depends on a range of factors, such as how far the different firms in the supply chain need to understand each other's processes, whether they work jointly on problem solving and to what extent they are concerned that their competitive advantage would be undermined by disclosure and so seek to protect their knowledge.'

The importance both to an end user and to a technology provider of understanding each other's needs and capabilities can be seen to be critical to the development of new technologies, and importantly the degree to which those technologies address business-critical issues of the end users. However, this situation can be seen to be further complicated in contexts such as the one associated with Enabler_1 (see section 4.2.1): 'Where innovation is being pursued across a network of organisations there are additional factors to consider, due to a large extent to the uncertainty and unpredictability of the innovation process. As innovation requires new knowledge to be created, knowledge issues are central to this unpredictability' (Quintas in: Little and Ray, 2005, p.256).

Critically then it is imperative for the technology providers to acquire new knowledge of the contexts and issues faced by the end users, if innovative new technologies are to be developed. This conditional ('know where' and 'know when') knowledge significantly influences the process of knowledge creation by the technology providers, and is a significant finding for the research. Although the relationship between innovation and knowledge creation is well identified in the literature (e.g. Nonaka and Takeuchi, 1995), no prior research exists which explicitly identifies the importance of the conditional knowledge of end users to the technology providers within the upstream oil and gas industry, and in the technology development process itself. This research then significantly builds on prior research by specifically identifying the importance of conditional knowledge not only to the knowledge creation process, but also within the technological innovation process.

The technology providers are also reliant on the acquisition of new procedural ('know how') knowledge in order to create technological innovations, and to continue to react to the changing needs of the end users. However in their reflections on the narratives, the data shows that (like the storage and maintenance of knowledge) the interviewees (specifically the technology providers) do not reflect on the creation of declarative knowledge in the form of new technologies as a formalised process within their own organisations.

This section previously identified that the technology providers are viewed by the end users as sources of declarative knowledge in the form of ideas new technologies, and the perspectives of the technology providers themselves support this view. However, as one interviewee from an end user organisation notes, the users of technology can also be seen to aid in the process of knowledge creation through personal interactions, not only with representatives from the technology providers, but also through sharing declarative knowledge relating to the sources of new technologies within the end user organisations themselves.

Although in this example the end users are not generating new knowledge themselves, they can be seen to be identifying potential sources of new technologies from the technology providers and also sharing their need for both declarative and procedural knowledge. This perspective can be seen to support Nonaka and Takeuchi's (1995) view of knowledge creation through the interaction between the tacit and explicit knowledge of individuals.

Although the interviewees' reflections on the narratives do not greatly add to the discussion pertaining to the process of knowledge creation within the technology providers, enabling organisation or the end users, the interviewees from technology provider organisations clearly highlight the importance of the financial support provided by the end users as a catalyst for the development process.

It is interesting to note that the provision of financial support in relation to the creation of new technologies was not identified within the first set of interviews. It is only when the interviewees reflect both on their own narratives and the narratives of other players, that finance is identified as an issue of concern for the technology providers in relation to the development of new technologies. Notably, McKenzie and van Winkelen suggests that it is inevitable for actors within the innovation process to reflect on what the returns on their technologies may be: 'Within any industry, it is also hard to foresee how the potential of ideas and knowledge will translate into reality. Will there be sustainable returns from a particular innovation? Will an idea be adopted or ignored' (Mckenzie and van Winkelen, 2004, p.137)?

However, the data shows that the technology providers appear to be more concerned with securing the funding in order to develop the technologies, rather than what the long term impact of the technology may be to the industry and the concomitant financial return. This relatively short-term perspective presented by the technology providers would appear to emphasise the difficulty in obtaining funding to develop new concepts and technologies, and the inherent problems associated with getting new products to market prior to their adoption (Amidon, 2003).

This in turn can be seen to impact on the use of Enabler_1 as a route through which the technology providers may present ideas for new technologies to the end users (Von Krogh, Ichijo and Nonaka, 2000), as data shows a degree of uncertainty on the part of the technology providers in the role of the enabling organisation in securing funding from the end users.

Again, the comments of the technology providers can be seen to highlight the difficulties in aligning with the strategic directions in place within the end user organisations relating to the areas within which they operate, and which subsequently impact on the ability of the technology providers not only in securing funding to develop technologies appropriate to those areas, but also in securing the commitment of the end users to apply those technologies once they have been developed. The ever changing strategic directions of the end users thus present a critical barrier to the creation of new declarative knowledge by the technology providers and to its subsequent application, as discussed in the next section.

5.6 Knowledge Application and Exploitation

Like the knowledge creation process, the application of knowledge can be seen from the data to be most closely aligned with the technology providers (see section 4.2.2.5) who can be seen to use their existing declarative and procedural knowledge to produce new technologies which meet the declarative knowledge needs of the end user organisations. Furthermore, the tacit declarative and procedural knowledge of the technology providers can be seen to be embedded in the technologies themselves, which are subsequently applied by the end users. Following on from the perspectives of Nonaka and Takeuchi (1995) in relation to the combination of explicit knowledge in order to create new knowledge and the role of learning as a knowledge-based process, Kogut and Zander introduce the concept of 'combinative capability' (Prusak (ed), 1997, p.18), whereby both current and acquired knowledge is synthesised and applied. They state that innovations are 'products of a firm's combinative capabilities to generate new applications from existing knowledge' (1997, p.27).

The technology providers can be seen to acquire and apply declarative knowledge of the needs of the end users to both their own declarative ('know what') knowledge of their existing technologies (which may subsequently be 'tailored' to the needs of the end users), and to the procedural ('know how') knowledge of producing new technologies based on the changing needs of the end users. This declarative knowledge of the end users is however not only limited to their technological requirements (in which identify the type of technology required within a given context), but also in transferring knowledge of a technical problem which may be solved through the application of the declarative and procedural knowledge of the technology providers.

The importance of applying knowledge from sources external to the organisation in relation to innovation activities is well identified within the literature (Cohen et al., 2002; Cockburn and Henderson, 1998; Chesbrough, 2003; von Hippel, 1988), and this can be seen to be acknowledged within the findings from the perspectives of both the technology providers and end users. The application of the declarative knowledge of the end users then helps to provide a form of orientation for the technology providers towards their customers, the end users themselves.

Customer orientation has been included by a number of researchers, and these have tended to fall into two categories (Chandy and Tellis, 1998; Veryzer, 1998). The first model has tended to reflect on the changes of behaviour required by end users in relation to the application of an innovation. Simplistically, this model suggests that the more radical the nature of an innovation, the greater the need for the end users to change their behaviour in order to effectively adopt and apply that innovation (Schiffman and Kanuk, 1997). However, an additional yet clearly related model of innovation which encapsulates customer orientation suggests that the more radical the innovation, the greater potential value of the innovation is to the end users and the greater advantages this has over existing products or services (Chandy and Tellis, 1998).

Unlike Nobelius (2004), this research suggests however that in this context there is no view that more radical innovations are perceived to be of more benefit to end users (see Sections 4.2.2.6 and 4.2.3.6) and indeed the context of the UK upstream oil and gas industry (as described in Appendix IV) and the perspectives of the end users suggest that there is a conscious avoidance of radical technological innovations due to the technical, financial and safety-related risks associated with new technologies, and again this is a significant finding for the research. This finding in particular can be seen to be of specific benefit to technology providers involved in the development of technological innovations for use within the UK upstream oil and gas industry.

Hislop extends his perspective (presented in the previous section) on knowledge creation to acknowledge other knowledge-based processes including the application of knowledge: '...while knowledge creation is an important aspect of innovation processes, so is the ability to search for and identify relevant external knowledge, and to blend and integrate different bodies of knowledge together' (2005, p.157). Related to this perspective, the end users can also be seen to apply their declarative knowledge of their technology requirements to the technology development process (see section 4.2.3.5) through the transfer of this knowledge to the technology providers (directly as well as via the enabling organisation). Additionally, the end users apply their own conditional knowledge of the contexts within which those technologies may be applied through their engagement with the technology providers.

As stated above, for the end user organisations the application of their knowledge within the technological innovation process can be seen from the interviewees' comments to relate to a number of specific areas such as the environments in which new technologies may be deployed (see section 4.2.3.5). Closely related to the processes of knowledge transfer and knowledge creation, the end user organisations can be seen as sources of declarative and conditional knowledge by the technology providers.

Critically, the intervention of the end users in the form of the application and transfer of their declarative and conditional knowledge to the technology providers can clearly be seen from the data to impact on the development of technological innovations, and thus provides an additional significant finding for the research. The importance of using customers (or potential customers in this context) as a source of knowledge is described by Amidon (1997, p.121): 'Customers have knowledge about your products and services. They also have knowledge of your competitors and their relative capabilities. They may even know more of your competitors' strategic direction that you might glean from a sophisticated competitive intelligence function of your own. More important, they know what they need – or at least what they think they need. They understand their own business challenges and what it takes for their business success. What they do not know – and what can be learned only through concentrated collaboration – is what is possible through an interlacing of their competencies with your own.' However, while Amidon does suggest the importance of customer (or end user) knowledge to the innovation process, she does not identify the types of knowledge. This research then furthers understanding of the role of knowledge within the technological innovation process by explicitly identifying the types of end user knowledge which may be used by technology providers in the development of new technologies, and is of importance both to practitioners within the innovation process (both technology providers and potential end users) and to academic researchers of innovation.

It is interesting to note that while the relationships between the processes of acquisition, transfer and creation are apparent through the interactions of the players, the representative from the enabling organisation does not consider it (the enabling organisation) to be involved in the knowledge creation process. However the data clearly indicates that the function of the enabling organisation as a knowledge conduit influences the application of knowledge by the technology providers.

While the interviews did not provide any additional findings in relation to how the actors apply knowledge within the context of their own organisations (following their use of the narrative system) or critically, how the end users apply the knowledge of the technology providers in the form of new technologies, the issue of funding the development of new technologies continues the discussion from the previous section and highlights the relationship between the creation of knowledge by the technology providers, and the application of that knowledge in the form of new technologies by the end user organisations. While the data emphasises the ability of the technology providers to generate new technologies through the application of their declarative and procedural knowledge, the data shows the different perspectives placed on the value of this knowledge by the technology providers and the end users, and the associated difficulties on behalf of the technology providers in securing funding to apply their knowledge (in the form of new technologies within the end user organisations.

The data shows that the end user organisations, while recognising the technology providers as key sources of declarative and procedural knowledge (see sections 4.2.3.4, and 4.2.3.5), are focussed on supporting the development and application of 'proven' technologies. This naturally presents a 'Catch 22 situation' (as stated by Contact_13) whereby the technology providers are unable to move from a conceptual stage of product development to the design and engineering stage (Rothwell and Dodgson, 1992), without the financial support of the end users, and the end users are unwilling to support the development of new technologies without having an explicit understanding that they will be able to subsequent apply those technologies successfully.

An additional factor identified in relation to the financial support to the development of new technologies was also highlighted by an interviewee from an end user organisation who suggested that while funding may be available within end user organisations, identifying where this funding may come from is another issue entirely. This again can be seen to impact on the ability of the technology providers to develop new technologies on behalf of the end users by extending the timescales in securing funding. This further adds to the frustrations expressed by the technology providers initially in using Enabler_1 as a potential route through to the end users, and then in relation to securing commitment from the end users themselves.

5.7 Knowledge Valuation and Measurement

The data shows that although the majority of the actors recognised the actual and potential value of the intellectual property of the technology providers in the form of the technologies, there was little indication of an explicit appreciation of the value of the intellectual capital of the organisations producing the technologies, or indeed of those applying those technologies (see sections 4.2.1.6 and 4.2.3.6) in the form of expertise by those organisations themselves.

The importance of the relationships between intellectual capital and innovation are highlighted by Narvekar and Karuna Jain (2006) who propose that the three traditional elements of intellectual capital (human capital, structural capital and relationship capital) are all essential elements of the innovation process. They do however also suggest that it is not only the three elements of intellectual capital which influence the innovation process: 'For the intellectual capital to manifest into new products or intellectual property there is a need for an intervention to facilitate innovation' (Narvekar and Karuna Jain, 2006, p.183). The specific nature of this suggested intervention will naturally vary according to the context within which it is placed, however the role of an enabling organisation could be seen to act to intervene by helping to establish relationships between the technology providers and the end user organisations.

From the perspective of the technology providers, the value of their intellectual property is inextricably bound into their declarative knowledge in the form of the technological innovations themselves and their procedural ('know how') knowledge in the form of their expertise. However while the potential value of the declarative knowledge embedded in the technologies was clearly recognised by the technology providers, the same was not so of their procedural knowledge. Indeed while Section 4.2.2.6 clearly indicates the concerns of the technology providers in relation to the protection of their intellectual property, there is no similar acknowledgement of the need to protect and maintain the intellectual capital of the staff within those organisations. Again, this can be seen to be a significant finding of the research. While prior research in the area does identify the importance of the protection of intellectual property in the innovation process (e.g. Helpman, 1993), this has tended to focus on the protection of declarative knowledge through the use of patents, and does not consider the relationships between the importance of procedural knowledge within the technological development process and the need to protect that knowledge. This finding then has clear implications for practice, and is of particular benefit to the actors involved in the technological innovation process.

Although the technology providers do not explicitly acknowledge the value of their own intellectual capital, the enabling organisation can be seen to have an implicit understanding of the intellectual capital of the technology providers in the form of their procedural ('know how') knowledge (see Section 4.2.1.6) which is subsequently shared with the end users. Thus in this context, it is the perception of value placed not only on the declarative knowledge of the technology providers, but also the procedural knowledge by both the enabling organisation and the end users that appears to dictate which technologies will be supported. Naturally enough, the value placed on both the technology providers and their technologies by the end users in highly dependent on the contexts within which those technologies and capabilities may be applied, and as Section 4.2.3.6 shows, is driven by the technological themes of the end users.

Twiss (1995, p.5) suggests that technological innovation can be seen as a process of converting 'scientific or technological knowledge directly into the satisfaction of a customer need; the product them becomes merely the carrier of the technology and the form it takes is only defined after the technology and the need have been clearly matched.' Thus, the perspectives of the end users are influenced by the degree to which the technologies developed by the providers satisfy their needs. As has already been mentioned, a number of the end user organisations use a thematic process to determine which technologies are of interest, and within those themes, rank technologies according to their perceived potential benefit to the organisation. However the data also shows that the value of the relationships between the technology providers and the end users (the relationship capital) is also a critical factor in determining whether a technology will be successfully developed and applied.

Following on from the perspectives of the technology providers and the enabling organization, the perspectives of the end users can be seen to relate more closely to the potential impact of the application of the procedural knowledge of the technology providers (in the form of new technologies) to specific areas of the business itself. Specifically these perspectives can be seen to relate to how effectively the technology providers can create a business case for the development of new technologies which in effect suggest the close relationships between the procedural knowledge of the technology providers and how this knowledge may subsequently infer their ability to produce declarative knowledge from this.

Additionally, the end users acknowledge difficulties in determining the ownership of intellectual property in instances where they have applied their own conditional knowledge to the development process. This issue highlights the commercial sensitivities of both the technology providers (who naturally wish to protect what they view as their own intellectual property) and the end users (who may perceive that the use of their conditional knowledge has contributed to the creation of new declarative knowledge in the form of a technological innovation), and also presents an inherent problem to the innovation process itself.

While the transfer of knowledge between the different groups of players can be seen to lead to the development of new technologies, the relative ease of knowledge transfer also leads to inherent difficulties in determining how those technologies have come into being, and who subsequently owns them. This relationship between the transfer of knowledge and the protection of intellectual property is an additional finding for the research. While there is a myriad of research into innovation networks and inter-organisational collaborations for innovation as identified within Chapter 2, this has tended to focus on the nature and types of interactions between organisations, and this research identifies for the first time the difficulty in establishing ownership of the output of these relationships in the form of new technologies. Additionally, prior research also exists into the contexts where organisations have developed technologies themselves, and has not acknowledged the issues (recognised within this research) which may arise in instances where end users also contribute their declarative knowledge to technology providers. Furthermore, this research can be seen to an additional perspective by highlighting these difficulties within the context of the UK upstream oil and gas industry, and again is of benefit to both practitioners and academics alike.

As was noted in section 4.3.1.6, none of the interviewees highlighted the valuation of knowledge following their reflection on the narratives. Despite this, there can be seen to have been an ongoing reflection on the financial difficulties surrounding the development of new technologies on behalf of the technology providers and the end users. The previous section highlights these difficulties, and in turn emphasises the difficulty in attributing value to knowledge: ‘Knowledge has nothing more than potential value until it is put to use in a way that the market recognizes as valuable. Assessing how potential will translate into realized value is largely a subjective judgement’ (McKenzie and van Winkelen, 2004, p.237).

In relation to this perspective, the technology providers can be seen to be limited in their ability to develop technologies which the market may view as valuable without the financial support of the end users. Again, the paradox presented by the technology providers relating to the exposure of their intellectual capital is evident, and furthermore shows the relationship between knowledge acquisition, transfer and valuation.

As the technology providers are sensitive to the risks in exposing their ideas for new technologies to the market in case their competitors develop competing products, the providers are less able to determine what the potential value of their declarative knowledge actually is. The issue of subjectivity identified by McKenzie and van Winkelen (2004) is apparent in this context, where the technology providers wish to emphasise the potential value of the technology in order to secure funding for development from the end users, and the users (as stated in section 4.2.3.6) need to prioritise their funding of technologies according to the strategic goals of the organisation.

While the discussion from the first part of the research highlights the importance of the protection of intellectual property by the technology providers, there was no reflection on this issue in the second interviews. In contrast, the data gathered from the second set of interviews highlighted the concerns of the technology providers (identified in sections 4.2.2.6 and 4.3.1.1) in relation to exposing their technologies and the protection of their ideas through the use of patents. Notably, the concern on behalf of the technology providers is not so much for the technologies themselves as the concepts which underpin them, and as such are less easy to protect.

5.8 Internet Mediated Narratives

The use of narratives and the narrative system developed in order to address the sixth objective set for the research can be seen to play an important role in relation to the interviewees' perspectives on the technological innovation process. Critically, the narratives present an opportunity for the interviewees to reflect on issues affecting the innovation process from both their own perspective and also from the perspective of the other interviewees. More specifically, the narratives allow the interviewees to reflect not only on the sources they may use to acquire knowledge, but also how and from where other organisations acquire different types of knowledge. The data shows that the interviewees (and specifically the technology providers) tend not to use the narratives to consider their own knowledge acquisition processes, but instead focus on how their own declarative knowledge is acquired by their competitors via the enabling organisation. This is a key finding for the research and contributes to the field of narrative research by acknowledging the ways in which narratives are used (specifically in this context by actors within the technological innovation process), and also to theoretical considerations relating to narrative knowledge.

The focus on knowledge acquisition routes is illustrated in the figure below which shows the actual acquisition of Provider_3's declarative knowledge by the enabling organisation (shown by a solid line), and subsequently the end users, and the concern of Provider_3 regarding the potential acquisition of its declarative knowledge by other technology providers (shown by a dotted line) via the enabling organisation:

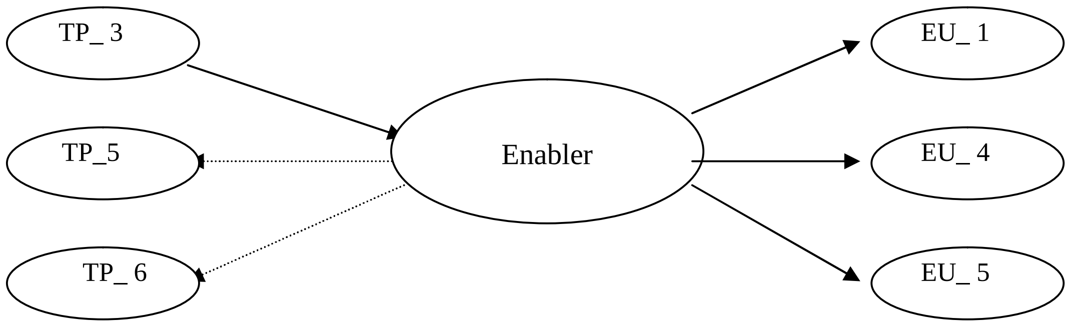

Figure 28: Potential Knowledge Acquisition Routes for Technology Providers

In relation to the use of narratives within the system and as a method for sharing knowledge, there can be seen to be significant amount of research in the use of narratives as methods for collecting qualitative data (Lienblich et al, 1998; Gabriel, 2000; Riessman, 1993; Boje, 2001). As a source of knowledge in their own right, Brown et al state that '...if knowledge is a source of wealth, rather than land, labor and capital, or more physical attributes, one of the ways knowledge is configured and transferred is through stories. And if that's the case, if knowledge really is a source of wealth, then stories become more valuable' (2004, p.45). Within the context of this research, the narratives are valuable from a research perspective as a source of data relating to the role of knowledge within the innovation process and are of benefit both to the researcher and to the actors within the innovation process.

Whereas in the first interviews, the technology providers can generally be seen to focus more on the innovation process in terms of the development of successful or ongoing projects, the second interviews highlight factors which can be seen to adversely affect the development of new technologies, notably the difficulties in securing funding from the end users and in using Enabler_1 as a potential route to the end users themselves. From the perspective of the enabling organisation, the interviewee can be seen to use the narratives as a mechanism to reflect on the experiences of both the technology providers and the end users in their engagement with the enabling organisation, and as such is used both as a mechanisms for confirmatory learning (i.e. to confirm the views and perspectives of the other actors) and as a method for gaining a greater understanding of these perspectives. From the perspective of the interviewee from the enabling organisation (Contact_1), the data shows that, although more time would have been beneficial in order to absorb the lessons contained within the various narratives, their value lay in the ability of individuals to develop an understanding of why the players were engaged within the process and the experiences they had gained through it. The end users similarly can be seen to use the knowledge to develop a better understanding of the experiences of the technology providers, and significantly to identify where the process of technological innovation may be improved through the relationships which exist between the actors.

As such, the actors can be seen to use the narratives in different ways in relation to its content. Viewed as a vehicle for storing and sharing explicit knowledge, the technology providers use the narratives as a method of acquiring declarative and causal knowledge and to use this to identify factors which impact on the development of new technologies. However, the data reveals that the interviewees from the end user organisations seemed to derive different benefits from their exposure to the explicit knowledge contained in the narratives, and in general seemed to have a clearer understanding of the types of learning which may be derived from the narratives.

Specifically, the interviewees from the end user organisations can be seen to acknowledge the difficulties in relation to the use of, and need for, anonymised data contained within the narratives due to commercial sensitivities. Rae states that: 'If we want to learn about people's perception of their experiences, we have to listen to and make sense of their stories' (Rae, 2000, p.149). This perception appears to be borne out in the perspectives of the end users who recognise the importance of the narratives in providing opportunities to develop a better understanding of the experiences of other players (both technology providers and end users) in their engagement with the enabling organisation. Like the technology providers, the end users also identify scenarios in which the innovation process has been adversely affected, however they can also be seen to use the narratives to consider areas for its improvement.

From the data it can be seen that a number of the interviewees acknowledged the issue of using anonymised data within the narratives themselves (see Section 4.3.2.4). As was stated in the previous chapter, a number of the interviewees had insisted on the narratives being made anonymous due to commercial sensitivities related to the development of new technologies. However, from the perspective of the interviewees as users of the system, the anonymisation of the data can be seen to have a detrimental affect on the value of the narratives themselves.

Although this was not an issue which the research sought to address, it can be seen to have a bearing on both the willingness of individuals to have their knowledge stored in an explicit form, and critically in the ability of individuals to share explicit knowledge which is commercially sensitive. Comparatively little research has been conducted in relation to anonymity and knowledge sharing, however Marx suggests anonymity is important in order to ‘facilitate the flow of information and communication on public issues’ and ‘to encourage reporting, information seeking, communicating, sharing’ (2001, p.101). Nevertheless in relation to the innovation process, this can clearly be seen to have an impact on the value of the knowledge shared.

Despite this, the data reveals that several of the interviewees (notably the technology providers and the interviewee from the enabling organisations) felt that a more pre-digested approach to the content of the system, particularly in relation to the technologies may have been more valuable to them. This in part may be due to the length of the narratives, and unwillingness on the part of the interviewees to derive personal meanings from the narratives through interpretation. Gabriel (2005) argues that a key part of ‘story-work’ within an organisational context is interpretation, however he goes on to state: ‘What has been less well analysed are the mechanisms through which an underlying set of meanings is generated, turning information into experience’ (2005, p.36). In relation to this research, there were concerns on the part of some of the interviewees that they were either unwilling or unable to generate meaning, and this were unable to turn the explicit knowledge embedded within the narratives into experience.

The engagement of the users with the narratives is not wholly due to the narratives themselves. The data shows that the structure of the system (including the system interface) can be seen to affect the users’ engagement (see section 5.2.3). Although only a small number of interviewees commented specifically on the system interface, it is nonetheless a significant factor in the design of websites. Although none of the users explicitly identified navigation as an issue, Shneiderman (2005) argues that ‘novice’ users not only made double the number of navigation errors when presented with a disorganised screen as more experienced users, but also had to think for double the length of time as an experienced user. Similarly in relation to e-commerce web sites, Turban and Gehrke (2000) identified navigation controls as an important factor in websites, and that users (perhaps unsurprisingly) prefer to use web sites which could be easily navigated.

One interviewee did note that the web site was rather bland. Although not necessarily significant in terms of the functionality and usability of the system, the comment does reveal an increasing expectation on the part of users in relation to the visual appeal of web sites. When designing the system, the requirement for the users to be able to compare stories (and thus compare the experiences of other interviewees) was identified as critical. Users were able to use different criteria when selecting stories for comparison. As well as being able to select by the individuals who had provided stories, users could also select by their role, and in addition select not only 'complete' stories but specific elements of stories.

The structure of the system was developed using a hybrid of narrative schema and the elements from soft systems methodology. Although the data reveals that although the users had little or no prior understanding of what those elements were, they were able to compare the stories effectively. However, this function was affected by the user interface as several users noted that when a large number of stories were selected, this made the narratives themselves less readable.

As was stated in the previous chapter, none of the users added any additional stories prior to the second set of interviews. However, a number of the interviewees made specific comments in relation to the interface for adding new stories, and can be seen from the data to be relatively divided in relation to how usable they felt this interface to be. Notably, one of the interviewees noted that while the interface was not necessarily a barrier to adding new material to the system, motivation on the part of the users may be an issue. This can be seen to strongly relate to the barriers of knowledge transfer as identified within the literature. Notably in relation to this research, Sun and Scott (2005) identify a range of imperatives from personal to organisational and inter-organisational imperatives. There can be seen to be little in the way of imperatives in relation to the narrative system developed as part of this research which may act to encourage users to add new material, and as such this acts as a barrier to knowledge transfer.

5.9 Summary of Key Findings

This chapter has presented a discussion of the findings from both the first and second parts of the main study. The findings are discussed in relation to the literature as it pertains to the innovation process, as well as the role of knowledge within this process. In addition to discussing the roles of the actors, the knowledge-based processes, and the forms and types of knowledge present within these processes, this section has also identified a number of key findings which are summarised below and revisited in the concluding chapter.

Acquiring Procedural and Declarative Knowledge

End users acquire both declarative and procedural knowledge of the technology providers through the enabling organisation. This research builds on prior theory by supporting the perspective of Al-Hawamdeh (2003) on the types of knowledge which may be acquired. In the context of the innovation process, this research highlights for the first time the types of knowledge acquired by the different groups of actors, and further contextualises this within the UK upstream oil and gas industry.

Conditional Knowledge Acquisition

The technology providers appear to acquire an additional type of conditional knowledge from both the enabling organisation and the end users which is not acknowledged in prior work in this area: 'know where'. In this context, this can be seen to be a form of conditional knowledge relating to potential environments (either geographical or technical) within which the technological innovations may be applied.

Absorptive Capacity and Knowledge Acquisition

The importance of the absorptive capacity of both the technology providers and the end users is critical to their ability to acquire knowledge. The absorptive capacity of the technology providers is critical to acquiring knowledge relating to the technological needs of the end users, and to their procedural knowledge needs in the form of expertise. The absorptive capacity of the end users is critical to their acquisition of the capabilities of the technology providers and knowledge of the technologies themselves. Additionally, the findings from the second set of interviews reveal an acknowledgement by the actors of the absorptive capacity of others, notably the technology providers, and the importance of absorptive capacity to the knowledge acquisition process.

Serendipitous Knowledge Acquisition

Despite the importance of the role of the enabling organisation as a source of knowledge for both the technology providers and the end users, the acquisition of knowledge of new technologies by the end users often happens serendipitously. The technology providers also acknowledge the importance of serendipitous encounters (in environments such as industry events) in identifying potential end users of technologies or sources of funding.

The Enabling Organisation as a Barrier to Knowledge Transfer

In relation to the transfer of knowledge, the enabling organisation can be seen to act as a conduit of knowledge allowing for a two-way exchange of knowledge between the technology providers and the end users. However, the enabling organisation acts to determine not only which types and forms of knowledge may be shared between these two groups of actors, but also which knowledge should not be shared due to issues such as commercial sensitivities. This finding contributes both to understanding the barriers to knowledge transfer, and to the roles of the actors within the technological innovation process. This finding is important both in academic and practitioner contexts.

Enabler Mediated Knowledge Transfer Threats

The technology providers also acknowledge the acquisition of their declarative knowledge by the enabling organisation and potential subsequent transfer of that knowledge to competitors as a risk to the development of technological innovations. Again, this issue can be seen to contribute to prior research relating to the identification of barriers to knowledge transfer, and also to understanding the role of knowledge within the technological innovation process.

Stored Explicit Knowledge

Although the enabling organisation actively stores explicit declarative and procedural knowledge relating to the technology providers, there was little indication of the types of explicit knowledge stored by either the technology providers or the end users. However, the technology providers store implicit and tacit declarative, procedural and conditional knowledge; and their declarative and conditional knowledge is updated through the acquisition of new knowledge via both the enabling organisation and directly from the end users. This research then acts to disprove prior research (such as Goh, 2005) which emphasises the importance of storing explicit knowledge within the technological innovation process, supports the perspectives of earlier studies (such as Abbey, 1983; Moorman and Miner; 1997; Tang, 1999), and further highlights the importance of the tacit knowledge of the actors to the technological innovation process within the context of the UK upstream oil and gas industry.

The Role of Conditional Knowledge in Knowledge Creation

The conditional knowledge of the end users can be seen to be a significant influencing factor for the technology providers in developing technologies to fit the needs of the end users. The findings show that the personal interactions between the technology providers and the end users lead to the development of new technologies or to incremental developments to existing technologies to suit the needs of the end users, and builds on the perspectives of Nonaka and Takeuchi (1995) on the relationships between knowledge transfer and knowledge creation. These interactions in the form of interventions by the end users through the application and transfer of declarative and conditional knowledge to the technology providers help to contextualise the declarative knowledge of the technology providers, and positively influence the innovation process itself.

The Importance of Radical Innovation

In direct contrast to the perspectives of Chandy and Tellis (1998) who suggest that the more radical an innovation, the greater its potential value to the end user, this research shows that the application of the technology providers' declarative ('know what') knowledge in the form of new technologies is more likely to be adopted by end users if the innovation is incremental rather than radical. This is a significant finding and has clear implications for practitioners and academics within the technological innovation process alike.

End User Intervention in Knowledge Application

Related to the key finding identified above regarding the role of conditional knowledge in knowledge creation, the declarative and conditional knowledge of the end users play a crucial role in the development of technological innovations. While the importance of customer knowledge has previously been identified in the literature, this research extends understanding by identifying the types of customer knowledge used by the technology providers and the importance of this knowledge to the technological innovation process within the context of the UK upstream oil and gas industry.

The Value of Procedural Knowledge

While the procedural knowledge of the technology providers appears to play a critical role in the technological innovation process, this research shows that there is little acknowledgement of the need to protect and maintain this knowledge. Prior research in this area has tended to focus on the protection of declarative knowledge in the form of the technologies themselves.

However this research suggests a need for the providers to acknowledge the value of their procedural knowledge, and also to find ways to protect it. Critically, this finding is of benefit to the actors (specifically the technology providers) involved in the technological innovation process.

Ownership of Intellectual Assets

While the transfer of knowledge between the technology providers and the end users clearly contributes to the creation of new declarative knowledge, this also leads to difficulties in determining the ownership of intellectual assets. While prior research does identify models of inter-organisational engagement within the innovation process, this has not identified the inherent difficulties associated with ownership of the outputs of these relationships and can again be seen to be of specific value to the actors participating within this process.

The Role of Narratives in the Reflective Process

The exposure of the actors to the explicit knowledge of others in the form of narratives does not appear to significantly influence the actors as detailed in the previous chapter. However the system does provide a useful environment in which explicit knowledge may be stored in narrative form, and subsequently transferred to the actors within the innovation process. The narratives themselves also provide a useful vehicle both for the interviewees to reflect on their own perspectives (and as such provide an additional level of validation to the data), and to gain additional insights from other interviewees despite the use of anonymised data. While the views of the users in relation to the content of the system are relatively mixed, there is an appreciation of the system as a vehicle for acquiring knowledge relating to the innovation process.

CHAPTER SIX: CONCLUSION

‘Industry, knowledge and humanity are linked by an indissoluble chain.’ (David Hume)

6.1 Introduction

The aim of this research was to further understanding of the role of knowledge within the technological innovation process within the UK upstream oil and gas industry. The research clearly shows the knowledge-based processes, and the forms and types of knowledge present within the technological innovation process, how these manifest themselves and their significance to the process as a whole. Furthermore the research also highlights the roles played by the actors involved in the technological innovation process, and the nature and significance of their knowledge-based interactions.

This chapter examines the contributions made by this thesis in its aim of furthering understanding of the role of knowledge in the technological innovation process. In addition the chapter presents limitations of the research, and considers directions for future research.

6.2 Contributions of the Thesis

Original contributions to knowledge derived from the findings of this research can be seen to relate to three main areas: contributions relation to the understanding of the technological innovation process within the UK upstream oil and gas industry; methodological contributions relating to the development and application of the research methods used; and contributions made through the philosophical perspectives adopted within the research.

6.2.1 Contextual Contributions

The research has made substantive contributions in relation to the understanding of the role of the different forms and types of knowledge within the innovation process, and also the knowledge-based processes present within the innovation process. The research can be seen to build on two key areas which were explored theoretically through a review of the published literature: the innovation process, and the concept of knowledge itself. The contextual contributions made by this research specifically relate to the following research questions:

Research Question 1: What prior research exists in the areas relevant to this research?

Research Question 2: Who are the actors within the technological innovation process in the UK upstream oil and gas industry, what are their roles, and what is the nature of their knowledge-based interactions?

Research Question 4: What knowledge-based processes occur within the technological innovation process, how do they manifest themselves, and what is their significance within this process?

Research Question 5: What forms and types of knowledge are utilised within the technological innovation process, how do they manifest themselves, and what is their significance within this process?

As discussed in the literature review, the emergence of what has become known as the knowledge economy has helped to create two clear links between knowledge and innovation. Firstly, knowledge can be seen to be an economic driver at all levels within the knowledge economy, from a national level where appreciation of the changing nature of work and the role of knowledge as a key intangible asset is clearly identified, down to a personal level where the tacit knowledge of individuals is being harnessed in order to develop products and services. Secondly, knowledge can be seen to have a critical role in the innovation process itself as described in this thesis.

Prior research within this area is limited. This has tended to focus on the relationships between specific knowledge-based processes (such as knowledge transfer) and the innovation process, the roles of the various actors, or in identifying the specific types of knowledge present within the innovation process. Additionally, a number of recent works examine the relationships between innovation and knowledge management, however these have largely provided examinations of organisations with formalised knowledge management initiatives. Furthermore the majority of these studies have examined the innovation process as an internal activity within organisations, and as such have not examined either the inter-organisational context or where formalised knowledge management initiatives do not exist. This research therefore represents the first attempt to bring together all of these elements in one study.

Adopting an evolutionary perspective on the innovation process, it is evident from the literature that knowledge has always played a critical role in the innovation process, and that there is a growing appreciation of the need to develop a better understanding of its role within this process. A number of gaps still exist in the literature relating to both knowledge and innovation (Darroch and McNaughton, 2002; Pyka, 2002; Dvir and Pasher, 2004; Denning, 2005; Scozzi et al., 2005), and this research has sought to go some way to addressing these shortcomings by examining the role of knowledge within the technological innovation process in the UK upstream oil and gas industry.

Based on prior research, this research identified three main types of actors within the technological innovation process in the UK upstream oil and gas industry. These were technology providers, enablers and end users. These types of actors can be seen from the relevant literature to be common across a wide range of industries. In addition to the identification of the actors within the technological innovation process, this research builds on relevant prior research by examining the nature of their knowledge-based interactions.

While the technology providers are seen as sources of declarative knowledge for the end user organisations in the form of the technologies which they produce, the research shows that despite attempting to protect their technologies through the use of patents, the providers are reticent about sharing information and knowledge about technologies with potential competitors. While understandable, the research shows that not only does this have an impact on their ability to secure funding for new technologies from the end users; it also affects the ability of the end users to adopt and apply those technologies. However, the end users openly share knowledge with their competitors relating to their technological requirements. Indeed, one of the functions of Enabler_1 is to identify technologies which may benefit a number of end users.

This research has shown that the success of the relationships which emerge between the technology providers and the end users as mediated by the enabling organisation (and consequently the successful development of technological innovations), is in large part due to the personal interactions, and in many cases the more informal aspects of the relationships which exist between the players themselves. Although placed within the context of what initially appears to be a highly structured process, the importance of developing and maintaining personal relationships is a significant factor. Indeed as the research has shown, these relationships carry on beyond their immediate need, and allow both technology providers and end users to identify potential participants within future projects.

By identifying the knowledge types present within the technological innovation process and showing how these manifest themselves and their significance to the process, this research contributes both to a deeper understanding not only of the technological innovation process and the role of knowledge within it, but also to the theory relating to the forms of knowledge by building on the work of writers such as Polanyi (1966), Nonaka and Takeuchi (1995) and Nickols (2000). Although the review of the literature revealed a variety of different classifications of the types and forms of knowledge, the research aimed to identify specific types and forms present within the technological innovation process.

In relation to the forms of knowledge, the research identified knowledge in tacit, explicit and implicit forms within the innovation process, and also how these forms of knowledge manifested themselves within the various knowledge-based processes. While all three forms of knowledge were in evidence, the tacit knowledge of the actors (individuals from the technology providers, the end users and the enabling organisation) can clearly be seen to have a significant role within the innovation process, and furthermore illustrates that the explicit knowledge of the actors plays a much less significant role within this process. This research has shown the contribution made by the tacit, implicit and explicit knowledge of the actors within the innovation process in the generation, development and application of new technologies, and has also shown the reliance placed by the actors not only on their own knowledge in various types and forms, but the knowledge of other actors with whom they engage.

In relation to this, the review of the literature reflected on the classification of knowledge based on the work of Polanyi (1966) and the subsequent misuse of this work by Nonaka and Takeuchi (1997), to the effect that it is insufficient to examine the states of knowledge in any context without also including implicit knowledge, which Nickols (2000) argues is knowledge that can be, but has yet to be, made explicit. Given this argument, explicit, tacit and implicit knowledge can all be seen to occupy important roles within the innovation process. This research reveals that explicit knowledge plays a much less significant role than both tacit and implicit knowledge, and thus develops prior research examining the relationship between the storage of explicit knowledge and innovation (which suggests that the codification and transformation of knowledge from a tacit into an explicit format has generally not affected the innovation process (Abbey, 1983; Moorman and Miner; 1997; Tang, 1999)) by clearly showing the significance of the various forms of knowledge and their interrelationships, and also how they manifest themselves specifically within the context of the technological innovation process in the UK upstream oil and gas industry.

In addition to these forms of knowledge, the research identified a number of specific types of knowledge present within the technological innovation process based on prior work of OECD (1996) and Alavi and Leidner (2001):

- Know What (Declarative Knowledge)
- Know Why (Causal Knowledge)
- Know How (Procedural Knowledge)
- Know Who (Declarative knowledge)
- Know When (Conditional Knowledge)
- Know With (Relational Knowledge)

The research shows that while all these knowledge types can be seen to be in evidence within the technological innovation process, the degree to which they manifest themselves varies within each knowledge-based process, and within each group of players. Specifically, the technology providers can clearly be seen to apply tacit procedural knowledge in the development of new technologies and declarative knowledge in relation to the technological needs of the end users. The enabling organisation applies and transfers declarative knowledge to both the technology providers and the end users in order to identify potential users of new technologies on behalf of the technology providers, and to identify the capabilities and existing technologies of the technology providers on behalf of the end users.

A significant finding for this research in relation to the types of knowledge was the identification of an additional form of conditional knowledge present within the technological innovation process: Know Where. This form of conditional knowledge (which was not identified by Alavi and Leidner (2001) or OECD (1996) in their identification of knowledge types) can be seen to be used within the technological innovation process in conjunction with 'know when' conditional knowledge in the identification of specific regions or contexts within which technologies may be applied. This finding not only furthers understanding of the types of knowledge present within the technological innovation process, but also contributes to the theory relating to the types of knowledge and specifically forms of conditional knowledge. Additionally, this finding can also be seen of benefit to both technology providers and end users within the technological innovation process by highlighting the importance for end users of sharing this form of knowledge with technology providers in order to develop new technologies which specifically address their technological needs in a variety of technical contexts.

Given the acknowledgement of the importance of the procedural knowledge of the technology providers to the technological innovation process, the research has also shown that there was little recognition on the part of the technology providers to protect this intellectual asset and builds on prior work in two key areas: firstly in the area of intellectual capital valuation by identifying the inherent value of this type knowledge to the technological innovation process; and also in the area of protection of intellectual assets which has traditionally focussed on the protection of the technologies themselves through the use of techniques such as patenting.

The research utilised an analytical template developed as part of previous research (Burnett et al, 2004) conducted in the UK upstream oil and gas industry in order to examine the knowledge-based processes within the technological innovation process. The processes identified and examined were:

- Knowledge Acquisition and Learning
- Knowledge Transfer and Dissemination
- Knowledge Storage and Maintenance
- Knowledge Application and Exploitation
- Knowledge Creation
- Knowledge Valuation and Measurement

This research has shown that despite occupying a key role in formalised processes of technological development (and indeed despite the role of the enabling organisation as a conduit of knowledge), the acquisition and transfer of knowledge between the actors (specifically in relation to the identification of relevant providers and their technologies by the end users) largely occurred serendipitously, and is identified as a critical finding for the research. This finding is of particular relevance to the actors within the technological innovation process. While serendipity is seen by the actors as beneficial (within environments such as industry conferences), this finding highlights the need to develop approaches or strategies which mitigate the likelihood of new technologies being developed through chance encounters between individuals, and are instead based on the ongoing formalised identification of technology providers and their capabilities in the form of procedural and declarative knowledge, and on the identification of the technological needs of end users.

While more recent generations of the innovation process highlight the importance of knowledge within it and notably formalising the transfer of knowledge between different actors involved within the process, these factors in their own right do not ensure that the organisations participating in the innovation process are utilising more recent models. Indeed, this research shows that both the technology providers and the end users utilise the simplistic technology push/pull models for the greater part. Although the UK upstream oil and gas industry was identified as by McNicoll et al (2002) as a 'knowledge industry', and as such the players within it may be expected to have a understanding of the innovation process, as Rothwell suggests this does not necessarily follow: 'The reality is more complex, in that even today all types of innovation process continue to exist in various forms. To some extent this diversity is a result of sectoral differences, i.e. innovation in certain consumer products has a strong market-pull flavour, innovation in assembly industries is becoming more integrated and parallel in nature, while innovation in science-based industries such as pharmaceuticals leans more towards the 'science discovers, technology-pushes' mode' (Rothwell, 1994, p.23). Thus, this research builds on and extends research into the innovation process by illustrating the manifestation of early models of the innovation process though the examination of the knowledge-based processes present within it.

Furthermore, this research also contributes to understanding of the nature of the technological innovation process specifically within the context of the UK upstream oil and gas industry by highlighting the adversity of the end users towards the use of radical innovations. While prior research (e.g. Chandy and Tellis, 1998) suggests that there is a perception that radical innovations are perceived to be of more value to end user organisations, this research has shown that this is not the case within the UK upstream oil and gas industry.

From the findings and discussion chapters, like the various types and forms of knowledge identified above, the knowledge-based processes can be seen to manifest themselves to varying degrees in relation to the actors within the innovation process. Notably the storage of explicit knowledge was not strongly acknowledged by any of the players within the sample group. Knowledge creation and the application of procedural knowledge by the technology providers are both integral to the innovation process, however the acquisition and transfer of knowledge by and between the players can also be seen to form a critical element. Specifically, the research identified the importance of absorptive capacity to knowledge acquisition on the part of both the technology providers and the end users, and the role of the enabling organisation as a route through which the end users acquire the declarative and procedural knowledge of the technology providers.

The perspectives of the interviewees in relation to the processes can be seen to be largely derived from the application of the analytical template, and it is worth noting that while the interviewees spoke at length about the innovation process itself and the interactions between the actors within the process, there was little recognition of the explicit role of knowledge or the knowledge-based processes in relation to the innovation process.

Although beneficial, the use of such frameworks is principally to act as a starting point for the examination of knowledge within different contexts. In consideration of the relationships which exist between the six knowledge-based processes, the research shows a critical relationship between the processes of knowledge acquisition and transfer within the context of the technological innovation process. Indeed the innovation process as a whole can be seen to be driven by the transfer and acquisition of knowledge between and by the technology providers and the end user organisations, as facilitated by the enabling organisation. As stated in the previous chapter, the difficulty in separating these two processes suggests a need to re-examine the processes themselves to consider knowledge exchange (a combination of knowledge acquisition and transfer) as a distinct knowledge-based process which is reliant on a two way exchange of knowledge between actors, where both actors as sources and users of knowledge.

Despite the importance of these processes in their role in supporting the technological innovation process as a whole, there was no formal acknowledgement of the importance of the management of knowledge within the innovation process by the actors themselves. This would support the view of Goh (2005) on the relationship between knowledge management (KM) and innovation management (IM): 'However, both KM and IM represent areas of management that seemed to reside in separate spheres of influence, with little or almost no impact on one another. One major difficulty confronting organisations involved in various KM activities lies in the need to improve innovation strategy continuously – to make the most efficient use of knowledge to create, better, faster and more cost-effective innovations so as to remain competitive' (Goh, 2005, p.7).

Beyond the knowledge-based processes which were utilised within the context of this research, a number of writers have also identified enabling factors which affect these processes. APQC for example propose four enabling factors: strategy and leadership; culture; measurement and technology (APQC, 2000 p.2). During the course of the research, it became apparent that these factors were also influential in the innovation process itself. Culture, and more specifically the importance of the factors which Davenport and Prusak (2000) and Pawar and Sharifi (2002) suggest influence the knowledge transfer process can be seen to have been acknowledged by the representative of the enabling organisation: *"If it had been Joe Bloggs I would have questioned whether it would have been realistic to do that, but in spending nine months, not working with the team but working alongside the team and getting* *to know them and working through the relationship, it gave us the confidence to say: "Yes, we are going to continue with this.""* (Contact_1, Enabler_1).

This research also identified a number of other factors which impact on the transfer of knowledge between the various actors which contribute to the understanding of the knowledge transfer process, specifically within the context of technological innovation. Notably, the use of procedural and legal arrangements by the enabling organisations was perceived by both the technology providers and the end users as a potential blocker to the transfer of knowledge, and more generally to the innovation process itself. This issue again highlights the complexity of relationships which exist between the different knowledge-based processes.

Furthermore, this research has also identified the role of the enabling organisation as a potential hindrance to knowledge transfer specifically between the technology providers and the end users by determining which knowledge may not be shared due to commercial sensitivities, and thus acts to further understanding of the issues which may affect the knowledge transfer process by building on the work of writers such as Davenport and Prusak (2000). The research also highlights concern of the technology providers that engagement with the enabling organisation may present an additional threat to the innovation process by exposing their declarative knowledge (in the form of the technologies) to their competitors, and again develops prior research in the area of factors affecting knowledge transfer.

An additional influencing factor on the transfer of declarative knowledge between the technology providers and the end users was also noted in relation to the funding of technological developments, and it is worth reflecting on the actors themselves in order to appreciate the significance of this finding. Related to this issue, the research has also recognised the inherent difficulty in determining ownership of intellectual assets in instances where both technology providers and end users have collaborated in the innovation process.

The importance of these contextual contributions can be seen in several ways. Firstly, this research contributes to the academic contexts of both knowledge management and innovation. Critically, the research can be seen to provide a detailed examination of the various knowledge-based processes, and their various relationships. As knowledge management as a discipline is often defined by these processes, this research presents an opportunity to revisit and extend these definitions. Again from an academic perspective, this research contributes to an understanding of the innovation process by showing the importance of the range of different knowledge-based processes present within it, and the forms and types of knowledge which are the content of these processes. Furthermore, the research also contributes to developing a deeper understanding of the specific relationships which exist between the actors in the innovation process, and their reliance on different forms and types of knowledge. Additionally, the research provides a detailed examination of the importance of knowledge within the technological innovation process specifically within the context of the UK upstream oil and gas industry, and thus aids in developing an understanding of this industry as a whole.

From an industrial perspective, this research emphasises the need for the actors within the innovation process itself to develop their own understanding of the importance of knowledge to the technological development process. In relation to this, this research has shown how the actors may acquire knowledge through narratives relating to the development of specific technologies. Furthermore this research has also shown the importance to the actors of understanding the different roles undertaken by the actors within the innovation process, and critically how these roles may affect (positively and negatively) the technological development process. Again, through their engagement with the narratives, the actors can be seen to reflect and evaluate these roles. This research then provides an opportunity to develop a better understanding of the role of knowledge within the innovation process both for the researcher and for the actors operating within an industrial context, and subsequently provides a basis for change.

6.2.2 Methodological Contributions

A key element of this research was the development of a methodological approach for the collection, analysis and structuring of data in narrative form. Broadly, this aimed to reflect the philosophical perspective of postmodernism in which narrative knowledge is viewed as valid as scientific knowledge (Lyotard, 1984), and in addition to contribute to the theory and use of research methodologies applicable within the social science context. The methodological contributions made by this research relate to the achievement of the following research questions:

Research Question 3: Can a methodology be developed to identify and examine the knowledge-based processes, and forms and types of knowledge within the technological innovation process?

Research Question 6: Are the actors within the technological innovation process influenced by exposure to the explicit knowledge of other actors, and if so how can this knowledge be codified and transferred?

The methodological approach utilised within this research aimed to determine both the forms and types of knowledge present within the process, as well as the specific knowledge-based processes as discussed in the previous sections. This research developed and tested a new methodological approach which is considered to be transferable to the analysis of the role of knowledge within other contexts, and thus makes a valuable contribution to the development of novel methodological approaches applicable to examining contexts within which knowledge plays a key role.

Specifically, the application of the content categories (identified in section 3.6) provided a robust methodology with which to examine the role of knowledge within the technological innovation process. However the use of such templates should be treated with caution as they provide a starting point for analysis, and other issues may emerge which fall beyond the categories used. Indeed the application of the template and the analysis of the data obtained from it directly aided in the achievement of the contextual contributions identified above.

In addition to the analytical template's application in relation to the forms, types and processes of knowledge, the research approach taken led to the successful development of a novel analytical template fusing elements of soft systems methodology and narrative analysis, and provided the structure for the narrative itself. While the integration of SSM and narrative schema was successful and is replicable in other contexts, it is debatable to what extent this added to the analysis of the data or to the understanding of the players within the innovation process. However, this may indicate that the analytical template used does not necessarily lend itself to the examination of the technological innovation process, but may be applied with a greater degree of success to the examination of other scenarios.

The methodology was reliant on the use of personal narratives from the actors within the innovation process. Research using narratives is becoming increasingly popular in the social sciences. However Lieblich et al (1998) suggest that despite the rise in interest in the use of narratives in research, one criticism levelled at narrative study is that it can be seen to be as much art as research: 'It seems based predominantly on talent, intuition, or clinical experience; defies clear order and systematization; and can hardly be taught' (Lieblich et al, 1998, p.1). While Lieblich et al may be unduly critical, in relation to this research; several factors relating to the use of narratives did emerge. Notably, the content and length of the narratives themselves can be seen to be variable, and are to an extent reliant on the ability of the individual to articulate their personal experiences effectively.

Dyer and Wilkins (1991) offer a valuable perspective which considers an important issue in relation to this research: the relationship which exists between the methodological approaches used in narrative-based research, and the content of the narratives themselves. Referring to Martin and Powers (1983) they suggest that: '…stories are often more persuasive and memorable than statistical demonstrations of ideas and claims. The classics we cite are, in every case, good stories more than testable theory. We can experience vicariously the relationships and ideas presented. We therefore remember them longer and understand them more complexly than had they been presented as a thin description of a construct or as a statistical table' (1991, p. 616). As such, narratives can be seen to be a highly effective method for transferring knowledge (as seen in this research), and the rise in the use of narrative research within the social sciences can also be seen to be an attempt to formalise and extend their use.

Another key methodological contribution made by this research was the development of the hypertextual narrative system. The system developed provided a mechanism whereby narratives could be stored, read, compared and added by its users. The purpose of the system was to determine if the actors within the technological innovation process were influenced by their exposure to the explicit knowledge of other actors and, if so, how this knowledge could be codified and transferred.

This research has shown that the use of such tools is beneficial in providing environments within which actors may reflect on their own perspectives or the perspectives of others. Critically, this research reveals that while the actors do not appear to alter their actions or behaviours in relation to the innovation process following their engagement with the narratives stored within the system. This finding can be seen to be of particular relevance both to researchers in the fields of narrative research and innovation, and indeed to developers of knowledge-based systems considering their potential impact on users.

Although limitations to the system were identified within the previous chapter, it did however provide an environment within which the users could learn about the experiences of other players, their engagement within the innovation process, and the relationships between the various players. Although the use of internet-based systems is by no means the only way of visualising the innovation process, it nevertheless provides a relatively secure and valid environment for storing and sharing knowledge within a potentially commercially sensitive environment. Additionally, the content can be readily updated and amended to reflect changes in the views and perspectives of the storytellers themselves.

The methodological approach also highlights an additional contribution in relation to the use of snowball sampling within research related to the innovation process. This research clearly illustrates the need to secure participation from end users of technologies prior to approaching technology providers. This can be seen to be due to the technology providers' unwillingness to identify the actual or potential end users of their technologies. By approaching the end users of technologies initially and securing their participation, this ensures that their disclosure of the technologies and the technology providers they are using encourages the participation of the technology providers without any breach of confidentiality agreements.

The importance of these methodological contributions can clearly be seen from an academic perspective. As stated in Chapter 3, the constantly changing societal contexts examined by social science drive the demand for new research tools which can be applied to examine these contexts. This research provides one attempt to develop a new analytical approach which can be applied not only to the examination of the innovation process, but also to other scenarios.

Additionally, the methodological approach taken can also be seen to be applicable within industrial contexts. Specifically this relates to the development of internet-based environments which can (as this research has proved) be used to store and transfer knowledge in the form of narratives. Although this has been tested within the context of the UK upstream oil and gas industry, it is clearly applicable to a range of industrial contexts.

6.2.3 Philosophical Contributions

A key element of this research was the acknowledgement of the philosophical standpoints of postmodernism and post-structuralism. Broadly, this aimed to reflect the perspectives of postmodernism in which narrative knowledge is viewed as equally valid as scientific knowledge (Lyotard, 1984), and post-structuralism in which the deconstruction of text emphasises the multiple meanings which may be attributed to works from differing perspectives (Norris, 1982). These philosophical perspectives manifested themselves in both the use of narrative interviewing as a method of data collection, the development of the narrative system designed to store explicit knowledge in narrative form, and the structure of that system which enabled the users to deconstruct the narratives into their component parts.

The findings indicate that both scientific and narrative knowledge are essential components of the innovation process if it is to lead to the successful development of a technological innovation. This perspective is recognised by the actors within the process itself, and they acknowledge that there are a variety of different strategies and approaches which may be used in the innovation process, any of which may (or may not) lead to the development of a technological innovation.

To an extent then, this may be considered as a recognition and adoption of the postmodern perspective by the actors within the innovation process in which there are no absolutes. However, there is a need to consider the degree of 'granularity' at which the postmodern perspective succeeds or fails. Within a structured process such as the innovation process with identifiable beginnings and endings, the postmodern perspective is beneficial in considering that there is no 'right' approach which leads to the development of a successful innovation. A myriad of approaches may be taken by each actor, and therefore there is no one 'truth' which can be universally applied to the process itself.

The methodological approach adopted within the research process can also be seen to adopt a postmodern perspective. Returning to the granularity issue, by breaking down the stories into their individual narrative schema components, this reduced the stories down to a point at which they were no longer meaningful and it is here that these philosophical perspectives become less useful as the components were less useful to the actors than the complete narratives.

Much of the literature relation to postmodernism relates to its use within artistic contexts such as the visual arts and literature, but even in these contexts modernism is still present. While the content of a novel may be considered 'postmodern' it may still be presented in a tradition form. Modernism and postmodernism (as was highlighted in the literature review) do not preclude each other. They can be seen to coexist. The acknowledgement of the role of qualitative research generally and more specifically the use of narratives and stories as both sources of data, and as mechanisms for sharing knowledge suggests a move away from the sterility of quantitative research which is much more akin to a modernist perspective. However, this does not negate the value of this approach, it simply emphasises that a number of equally valid approaches may be adopted, and it is the context in which these approaches are applied which decides their usefulness.

A postmodernist perspective can be successfully applied to a structured modernist context such as the innovation process. Its usefulness is in acknowledging that there is not one innovation process, but many. The actors may learn from each of these processes (knowledge of which may be shared through narratives), and arguably this is a more valuable perspective and opportunity for learning. This is reflected through the importance of a collection of individual narratives which presented, in some instances, conflicting accounts of the roles and values of the different organisations. The actors themselves acknowledge the importance of the differing perspectives taken by their peers, and did not suggest that the narratives were right or wrong, simply that different approaches had been taken.

The attempt to adopt different perspectives in social science research is perhaps as important as the intrinsic value added to the research by the postmodernist perspective. Within this research it was an important and valuable perspective for a number of reasons: firstly, Lyotard's view of narrative knowledge (1984) which the research bears out; and Klage's view of the 'codifiability' of knowledge in computerised form is also borne out to a lesser degree (2003). The use of narratives as a source of knowledge and as a source of data for social scientists was critical to the research process, and through the use of narratives, subsequently contributes to the philosophical perspectives of postmodernism and post-structuralism

Again, the importance of adopting specific philosophical standpoints in social science research is reflected in the previous section which emphasises the importance of the development of appropriate methodological tools which can be applied to the examination of social contexts. The perspectives presented by both postmodernism and post-structuralism can be seen to philosophically underpin these social contexts, and are in effect an intrinsic part of them.

6.3 Limitations of the Research

As well as acknowledging the successes of the research, it is important to reflect on areas in which the research may have been improved upon. These can be seen to be related to the contextual and methodological contributions identified above.

Firstly, the scale of the research was inherently limited by using actors involved in the innovation process who had engaged with one enabling organisation, and their degree of participation. However this enabling organisation is in a unique position in terms of the type of engagement and support it provides to the development process of innovative new technologies within the UK upstream oil and gas industry, and thus while the sample size is relatively small, it remains valid due to the significant role played by the enabling organisation and the number of participants (both technology providers and end users) who participated in the study in terms of the population size. As stated in Chapter 3, Fowler (1993, p.19) states that: 'How well a sample represents a population depends on the sample frame, the sample size, and the specific design of the selection procedures.'

Given the nature and sensitivities of the topic of technological innovation, there were inherent difficulties in securing participants within the research. Although the anonymity of the interviewees, their organisations, and projects was protected as far as was possible, several potential interviewees did not participate in the research due to concerns over commercial sensitivities. This in turn can be seen to have affected the size of the sample group used as a source of data.

Specifically, as the research aimed to examine ongoing relationships between the technology providers, enabling organisation and the end users, the currency of those relationships can be seen to affect the willingness of the interviewees to participate. In relation to this, the use of anonymised data in the content-rich environment of personal narratives could be seen to devalue their worth to other potential users of the narrative system.

As noted in Chapter 5, the commercial sensitivities surrounding completed technological development projects are substantially reduced and, in retrospect, consideration may have been given to examining situations where the relationships between the players had terminated at the successful development of a new technology. However, this may not have provided the research with additional perspectives from the interviewees relating to barriers to the innovation process, and indeed the retrospective reflection on the process by the actors may have provided a less accurate account compared to the examination of ongoing projects.

In relation to the forms of knowledge identified within the research, the subject of differentiating between knowledge and information remains a challenging one. Although this research did not seek to identify and address the relationships, differences and similarities which exist between knowledge and information, it is important to acknowledge that the debate surrounding this issue is far from conclusive, and as such any research which uses any models of information and knowledge should recognise this. The work of Polanyi (1966) can be seen to be critical to understanding tacit and explicit knowledge, and the use of Polanyi's work as a basis for Nonaka and Takeuchi's models (1995) remains a contentious issue.

In addition to the factors noted above, methodological limitations of the research can be seen in relation to the conversion of spoken to written narratives. While recording narratives provides a valuable opportunity to gather large amounts of data in a relatively short space of time, the research was reliant on translating these into a form which could then be stored in a written form, and consideration could have been given to other methods of capturing the narratives in a visual or spoken form. However, this again may have presented a further level of complexity in relation to the issue of anonymity identified above.

6.4 Future Research

Although the research itself has achieved its aim of furthering the understanding of the role of knowledge within the technological innovation process and developed a methodological approach which proved reliable and replicable, it also raises a further set of research questions which may be addressed by future research. Again, potential areas for future research have been identified in relation to the contextual and methodological contributions made by this research.

As with all social science research, one obvious opportunity for future research is to apply a similar approach within different contexts. Pertinent to this research would be to examine the role of other enabling organisations within this sector. Although there are no organisations within the UK upstream oil and gas industry with a similar remit to the enabling organisation examined within the context of this research, seen from a global perspective the industry can be seen to incorporate a range of similar types of organisations within different geographical regions. Additionally, a broader perspective may be placed on future research which may be to examine the role of knowledge within the technological innovation process in other ‘knowledge intensive’ sectors such as software development or information technology hardware.

The identification of knowledge processes in different contexts can be seen to be a critical area for future research. This research has highlighted the complexity in the relationships between these processes (and in particular the relationship between knowledge acquisition and transfer), and the review of the literature reveals that any holistic classification of knowledge-based processes is far from evident. However, it is debatable how beneficial such a classification would be without first developing an understanding of the contexts within which they are observed.

In relation to this research, while impeding the transfer of knowledge, the use of procedural arrangements by the enabling organisation was intended to attempt to protect the intellectual property of the technology providers. Although within the context of this research, the issue of intellectual property has been dealt within the context of the valuation and measurement of knowledge, this may not be an adequate reflection of the importance of knowledge protection in its own right. As such, the knowledge processes themselves may be reappraised and extended to reflect their relative significance and relationships within different contexts such as different organisational processes, different industry sectors, or geographical areas.

As noted in Section 6.2.1, the relationship between knowledge acquisition and transfer, and the inherent difficulty in viewing these as two distinct processes also indicates considerable scope for future research in the examination of the relationship between these processes in both theoretical and practical contexts. As this research has highlighted, personal interactions act to catalyse and enable the acquisition and transfer of knowledge between individual actors, and indeed may also act as inhibitors to this process. Give this, consideration could be given to the application of techniques such as social network analysis to examine further the role of social/personal interactions within the context of the technological innovation process.

As with the knowledge-based processes, there is no consensus on the enabling factors which affect each of the processes. Indeed, while barriers to knowledge transfer are well identified within the literature, barriers to processes such as knowledge valuation are less well understood. There can be seen to be a need to develop a better understanding of the enabling factors surrounding these processes, and to what extent these may influence or affect the processes themselves.

Future research could aim to identify what these factors are, and to what extent they affect the different knowledge-based processes. It is likely that as with this research, that the enabling factors will affect the processes to different extents (both qualitatively and quantitatively) within different contexts such as different organisational sectors (as with this research), different types of organisations, and even different geographical locations.

Related to this, both the types and forms of knowledge identified may be examined in different contexts, and in addition their roles within the knowledge-based processes identified in this research. As identified in the previous section however, the debate surrounding the relationships between information and knowledge is ongoing and (given the nature of the field of epistemology) unlikely to be concluded.

There can be seen to be considerable scope for future research in relation to the methodological approach used within this research in other contexts, or developing further variants based on the knowledge processes, forms and types of knowledge, narrative schema and soft systems methodology. As the approach taken was a hybrid approach based on narrative schema and soft systems methodology one possible approach could be a fusion of knowledge mapping and rich picture methodologies as there are currently no formal techniques or processes for either knowledge mapping or developing rich pictures (Checkland and Scholes, 1995, p.4).

6.5 Concluding Remarks

This thesis has suggested that while knowledge and the processes which underpin its management play a critical role in the technological innovation process in the upstream oil and gas industry, the explicit understanding of their role by the actors within the process is limited.

By developing a greater understanding of the role of knowledge and the knowledge-based processes within the technological innovation process, this research has sought to develop a deeper understanding not only of the role of knowledge within the technological innovation process on the part of the researcher, but also on the part of the participants within the study. The research has identified critical factors affecting the role of knowledge within the innovation process, notably the ability and willingness of the actors to share declarative knowledge. The research has added to the existing material relating to the innovation process by explicitly identifying the forms and types of knowledge present within the innovation process, and the engagement of each group of actors in relation to six knowledge-based processes. It has also added new material relating to the understanding of knowledge-based processes and their relationships, and the types of knowledge present within the technological innovation process. From a philosophical perspective the research has also shown that both scientific and narrative knowledge play critical and indeed complimentary roles in the technological innovation process on behalf of the actors.

Critically, the research identifies six knowledge-based processes which take place within and between the actors within the technological innovation process. While the theory surrounding these processes presents them as having significance in the examination of the role and use of knowledge within different contexts, this research has shown that these cannot be accorded an equivalent importance within all contexts. Within the technological innovation process in the

UK upstream oil and gas industry, the key focus of the actors on these knowledge-based processes can be seen to surround the exchange of knowledge between the different groups of actors, and notably identifies a significant role for enabling organisations in facilitating this exchange between the providers and developers of potential new technologies, and those organisations seeking to benefit from these. The tacit procedural and declarative knowledge of the technology providers can be seen to be the key source of ideas leading to the development of new technologies for the UK upstream oil and gas industry. However, there is a critical role to be played in identifying where, when, and how this knowledge may be applied. This role, played in part by the enabling organisation studied within the context of this research, is as a conduit of knowledge between the technology providers and the end users of technologies.

In 2007, oil and gas from the UK Continental Shelf (UKCS) provided approximately 70% of the UK's total energy demand. Since the discovery of oil and gas in the UKCS, over 37.5 billion barrels of oil equivalent have been produced, and there is still an estimated potential for the recovery and production of a further 25 billion boe (UKOOA, 2009). The need for innovative new technologies to aid in exploration and production of oil and gas in the UKCS is undiminished, and is arguably more pressing than ever. It is through the engagement and collaboration of organisations such as those examined within the context of this research that such technologies are developed, and not only aid in the continuing survival of the organisations which apply these technologies but the UK upstream oil and gas industry as a whole.

Technological innovation within UK oil and gas industry remains a critical factor for its ongoing survival within a global economy, and until viable sources of renewable energy are developed, the UK oil and gas industry will continue to act as a key source of revenue and energy for the UK. Although often viewed as an industry in decline, Deffreyes notes that the focus on the use of innovative new technologies to aid in the recovery of oil and gas should continue, albeit with the caveat that returns on their use may not happen immediately: 'Lots of cleverness, time, and money have gone into enhanced recovery projects. That doesn't mean we should stop thinking about enhanced recovery and trying good ideas. It does mean that we'd better not count on using the remaining oil for at least a decade' (Deffeyes, 2005, p.28). This research has shown that knowledge and the processes which underpin it have played and continue to play a critical role in the technological innovation process in the UK upstream oil and gas industry. However, this research has also revealed that despite this critical role, its understanding on the part of the actors within the process is limited, and that the knowledge-based processes themselves may be managed more effectively by the actors. Broadly, the research has a number of potential implications for both academics and practitioners. Firstly, by developing a better understanding of the role of knowledge within the technological innovation process, the practical knowledge and understanding of the process on the part of the actors within it may be improved and as such lead to the improvement of the technological innovation process itself. Secondly, as stated above, developing an understanding of the knowledge-based processes and forms and types of knowledge builds on existing theories relating to knowledge and also leads to a better understanding as to how these may be managed more effectively within contexts such as the technological innovation process.

Thus, given the significance of the innovation process to the knowledge economy, and more specifically the significance of the upstream oil and gas industry to the UK economy, the findings for this research are potentially far reaching. If adopted, these findings could help to continue and extend the economic viability of the UK upstream oil and gas industry through the development of more efficient technological innovation processes for the 21st Century.

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APPENDIX I: Sample Organisations

End User_1

End User_1 is a multi-national exploration and production company which finds, produces and transports oil and gas to market. It operates in nearly 100 countries, employs around 100,000 people, and has been in existence for around 100 years. The strategy of the company is to invest to grow production efficiently by focusing on accessing, finding and developing the largest fields in the world's most prolific hydrocarbon basins; building leadership positions; using technology to improve productivity and support new access; and managing the decline of existing producing assets.

End User_2

Established in 1989, End User_2 is one of the largest independent crude oil and natural gas producers in the world. The company continually targets cost effective alternatives to develop its portfolio of projects. The company has a low-cost, diversified combination of assets in North America, the North Sea and Offshore West Africa. In the United Kingdom part of the North Sea, its focus is on managing its infrastructure, platform maintenance and mature basin exploitation in order to prolong the life and economic value of its assets. It also maintains a large inventory of drilling locations to maximize our development projects and infill drilling. Its strategy for the North Sea is to stabilize production and plan for modest growth. Mature field declines will be offset with development projects and infill drilling.

End User_3

End User_3 is a major integrated energy company which operates in the areas of finding, producing, transporting, transforming and marketing oil and gas. As well as its oil and gas business, the company operates in electricity generation and sale, petrochemicals, oilfield services construction and engineering industries. The company dates back to the 1920s and is active in 70 countries with a staff of about 80,000 employees. The company is committed to investing in technological innovation and energy efficiency.

End User_4

End User_4 is a global group of energy and petrochemical companies which operates in around 100 countries, employs approximately 100,000 people, and is over 100 years old. Its exploration and production base is in Aberdeen where it directly and indirectly employs around 6,500 people, both onshore and offshore. The company was one of the first to develop oil and gas fields in the North Sea, and has invested there since 1965. All of its UK oil and gas production comes from the North Sea. The strategy of the company places technology and innovation at its core, and it believes these will impact positively in the growth of the business.

End User_5

End User_5 is a global, diversified, upstream oil and gas company which was established in 1992 and has around 2,500 employees. Its three main operating areas are North America, the North Sea and Southeast Asia. The Company also has a portfolio of international exploration opportunities. The Company is pursuing opportunities in the North American unconventional natural gas business, as well as development opportunities in Southeast Asia and Norway. It is shifting its international exploration portfolio toward high-impact prospects which will support the ongoing renewal of the Company.

End User_6

End User_6 is one of the world's largest international oil and gas companies and dates back to the mid-1920s. Its operations include upstream operations (oil and gas exploration, development and production) and downstream operations (refining, marketing and the trading and shipping of crude oil and petroleum products). It operates in over 130 countries and employs over 95,000 employees world wide. It is the fourth-largest operator in the UK North Sea where it is licensed to explore for and extract oil and gas. Its exploration and production headquarters are in Aberdeen, Scotland. The company also produces base and specialty chemicals for the industrial and consumer markets and has interests in the coal mining and power generation sectors. It is also committed to developing renewable energies such as solar power and marine energy and second-generation biofuels.

End User_7

With origins dating back to the late Nineteenth Century, End User_7 is one of the world's largest integrated energy companies. Headquartered in the USA, it is engaged in exploration and production, manufacturing, marketing and transportation, chemicals manufacturing and sales, geothermal energy, and power generation. It is also investing in renewable energies and advanced technologies. The company employs around 60,000 people worldwide. Its global upstream strategy is to grow profitably in core areas, and it is reliant on the use of innovative technologies to improve its chances of finding, developing and producing crude oil and natural gas.

Provider_1

Provider_1 are a small private limited company incorporated in 2007 with around 20 employees. The company specialises in the creation, development, implementation and commercialisation of innovative technical solutions in the field of pipeline integrity in both the oil and gas industry and the water industry. The company is currently aiming to become a leading service provider in the field of well integrity. The winner of a number of recent awards relating to their technologies (including an award in the Innovative Technology category at the Scottish Offshore Achievement Awards), the company was a university spin-out and is based in Aberdeen, Scotland.

Provider_2

Provider_2 is a small private limited company formed in 2003 and incorporated in 2007. The company currently employs around 35 staff and is a service sector supplier to the oil and gas industry providing drilling, completions, fishing and well services. The company places an emphasis on the provision and servicing of high quality products. Provider_2 has also won a number of recent awards including awards in the Grampian Awards for Business Enterprise New Business and Young Business categories, and the ‘Sir Ian Wood Award for Innovation’. The company has submitted a number of patent applications in its own name, and its managing director is named as the inventor in 30 patents for down-hole tools and completions products. It has also acquired three further companies also involved in the development of down-hole tools.

Provider_3

Provider_3 was also formed in 2003, and based in Aberdeen, Scotland. The company initially began as a mechanical engineering company which provided engineering services to service as well as exploration and production companies operating in the oil and gas industry. The company has expanded rapidly since its inception, approximately doubling its revenue every year. The company employs around 30 members of staff, and supplies and installs a wide variety of patented products. The company was recently names the improved oil recovery category winner of E&P magazine's ‘Meritorious Award for Engineering Excellence’ for one of its technologies.

Provider_4

Provider_4 was established in 1993, and is based in Texas, USA. It is an engineering company which supports well intervention and drilling in the upstream oil and gas industry. The company is a worldwide provider of advanced coiled tubing monitoring devices, data acquisition systems, and modelling software. The company employs around 20 industry specialists including engineers, programmers, technical writers and trainers. Approximately 40% of the company's revenue comes from software for coiled tubing, wireline and jointed pipe (drilling and well completion) applications, with the remainder coming from engineering products and consulting. The company is 75% owned by employees and 25% owned by other large service companies in the oil and gas industry.

Provider _5

Provider_5 was established by in 1999 with the mission to provide new advanced offshore technologies for oilfield decommissioning in the North Sea and other key oil producing areas worldwide. More specifically, the company is involved in offshore decommissioning projects, and is experienced in marketing key technologies within the offshore structure management and abandonment applications. The company employs around 10 people based in Aberdeen, Scotland including a design and engineering team dedicated to providing cutting solutions.

Provider_6

Provider_6 supplies a range of downhole products and services to the global oil and gas industry, specialising in remote open close technology. The company has won a number of awards including 'Most Promising Small Company' and 'Innovative Technology' at the Scottish Offshore Achievements Awards. Founded in 2003, the company has filed for patents on 12 products, and currently employs around 50 people in the Aberdeen area of Scotland.

APPENDIX II: Users' Guide to the Innovation-Narratives System

1. Introduction

The Innovation Narratives System is a repository of stories relating to the development of technological innovations for the upstream oil and gas industry. The stories contained within the system have been provided by technology providers, enablers and end users.

2. Welcome Page

The first page on the website displays a welcome message, and a hypertext link allowing registered users to log in to the system. If you have been given a user name and password for the system, you may follow this link, which will take you to a log in page.

3. Log in Page

By entering the user name and password you have been given (both of which are case sensitive) and pressing the 'login' button, you can access the repository of stories.

4. Home Page

The home page of the Innovation Narratives System provides you with three hypertext links, each of which gives access to different functions within the system. These links are also duplicated on the navigation bar at the top of the page. The three links are:

Write
Read
Compare

In addition, an email link has been provided should you experience any problems in using the system.

5. Write a Story

By following the 'Write' link, you will be directed to a new page which allows you to add a new story to the Innovation Narratives System. The page contains the following sections which are designed to help you structure your story of a technological development you have been involved with. It is recommended that you read some or all of the stories currently contained within the system prior to writing a new story in order to understand the story structure.

Author – This field should be filled in automatically, and is taken from your login details. It is not displayed to other users.

Author's role – This is a drop-down list from which you may select your role according to your involvement with the development of a technology. You may select from the following roles:

Provider – the provider/developer of a new technology
Enabler – an enabler of the development of a new technology and/or the innovation process
End User – the end user (potential or actual) of a new technology

Story Title – A blank field allowing you to provide a title for the story.

Abstract – A blank field allowing you to enter an abstract or prologue providing a title and summary of the situation to follow.

Orientation – A blank field allowing you to enter an orientation for the story, providing a description of the present state of affairs (including place, time, customers, actors and owners of the process)

Exposition – A blank field allowing you to enter an exposition for the story, providing information about past events which have bearing on the present including environmental constraints and Weltanschauung (or 'world view')

Initiating Event – A blank field allowing you to enter an initiating event for the story altering the present state of affairs

Goal – A blank field allowing you to enter a goal for the story, providing a statement of intention or an emotional response to an initiating event by a protagonist

Complicating Action – A blank field allowing you to enter a complicating action for the story (linked to an antagonist) arising as a consequence of the initiating event and presenting an obstacle to the attainment of the goal

Resolution – A blank field allowing you to enter a climax or resolution for the story ending the conflict between goals and obstacles and establishing a new equilibrium or state of affairs

Epilogue – A blank field allowing you to enter an epilogue for the story providing the moral lesson implicit in the history of the events and (potentially) including explicit character reactions to the resolution

Whole Story – A blank field allowing you to write the whole story, rather than the individual sections.

Save Story – Once you have finished writing your new story, you can click on the 'save story' button which will save your story within the system. Once you have clicked this link, you will be directed to a page confirming that your story has been saved.

6. Read a Story

By following the 'Read' link you will be directed to a new page which contains a drop-down list of all the stories currently stored within the system. The drop-down list orders the stories using codes given to the organisations and individuals within those organisations who have participated within this project. The codes have been given to the organisations and the individuals in order to ensure their anonymity.

By selecting a story from the drop-down list and clicking on the ‘Read Story’ button, you will be directed to a new page with the whole story you have selected. In addition, at the top of this page, the same drop-down list of stories is provided allowing you to select a new story to read.

7. Compare Stories

By following the ‘Compare’ link you will be directed to a new page which provides you with a number of options allowing you to compare different elements of the stories you select. The page is divided into three sections:

Compare – this section allows you to select different elements of the stories. You can select as many or as few as you wish. For example you may select only the initiating events of stories, or the expositions, orientations and initiating events of stories.

By – this section allows you to further narrow down your selection of stories on the following screen by clicking on one of the following radio buttons:

Role – by clicking on this radio button, a drop-down list becomes available below in the ‘Choose’ section, which allows you to select stories (or parts of stories) from the technology providers, enablers or end users.

Selection – by clicking on this radio button, this allows you to select from all the stories (or parts of stories) currently stored within the system.

Author – by clicking on this radio button, a drop-down list becomes available below in the ‘Choose’ section, which allows you to select from all the stories (or parts of stories) of one author.

By clicking on the continue button at the bottom of the page, you will be taken to a new page which will display stories which match the criteria you have just selected in the ‘By’ and ‘Choose’ sections. On this page, you can select the stories you wish displayed by using the tick-boxes provided. You may select as many or as few as you wish. Once you have done this, you can click on the ‘Compare’ button which will take you to a new page where the stories (or parts of the stories) that you have selected are displayed side by side.

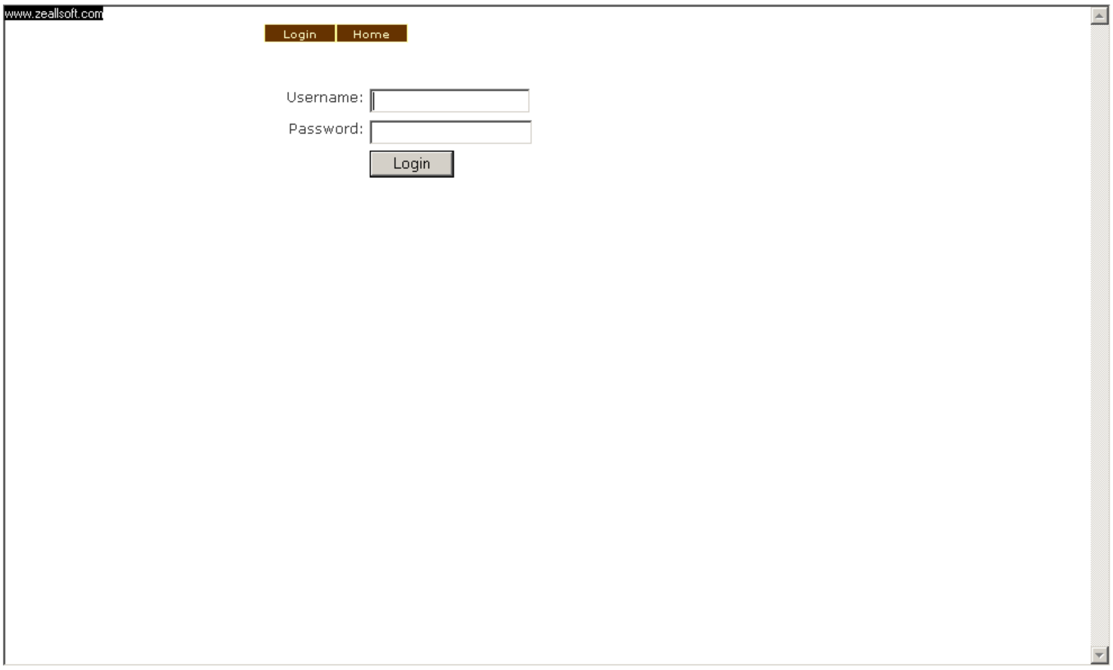
8. Logout

Once you have finished using the system, you can logout securely using the ‘Logout’ button on the navigation bar at the top of the page.

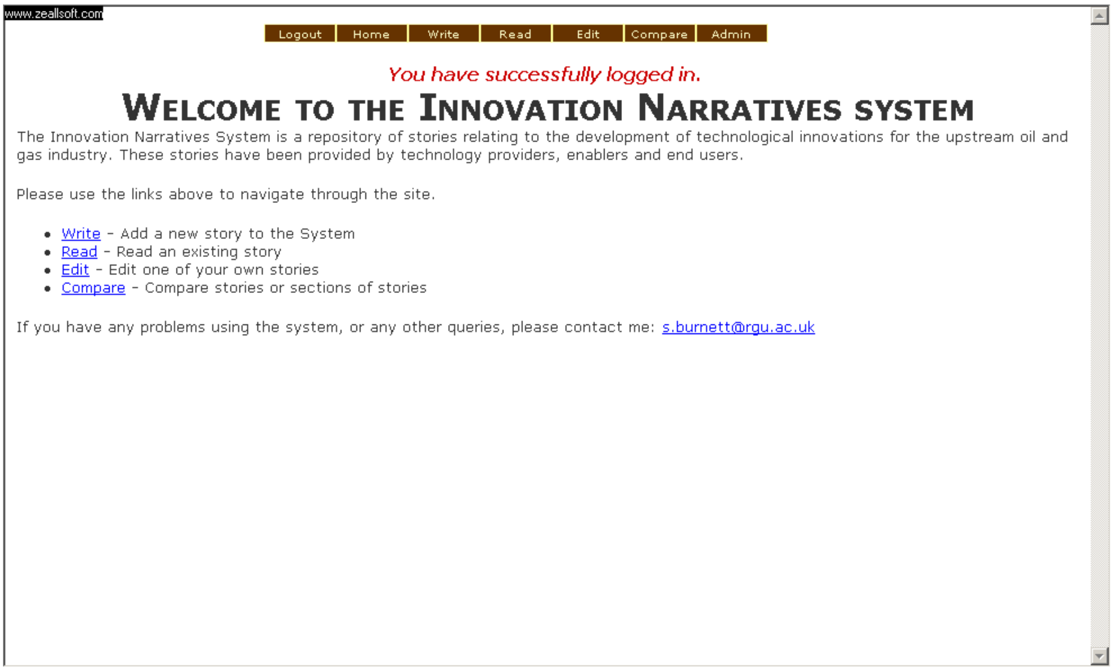
APPENDIX III: Narrative Tool Screenshots

FRONT PAGE

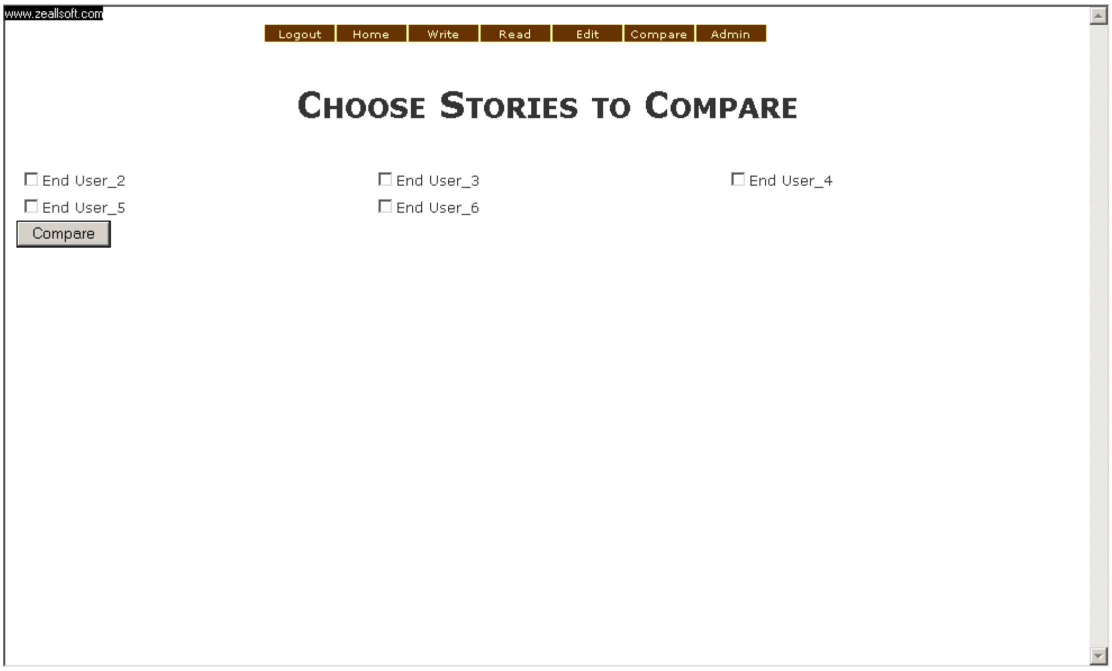
USER REGISTRATION PAGE

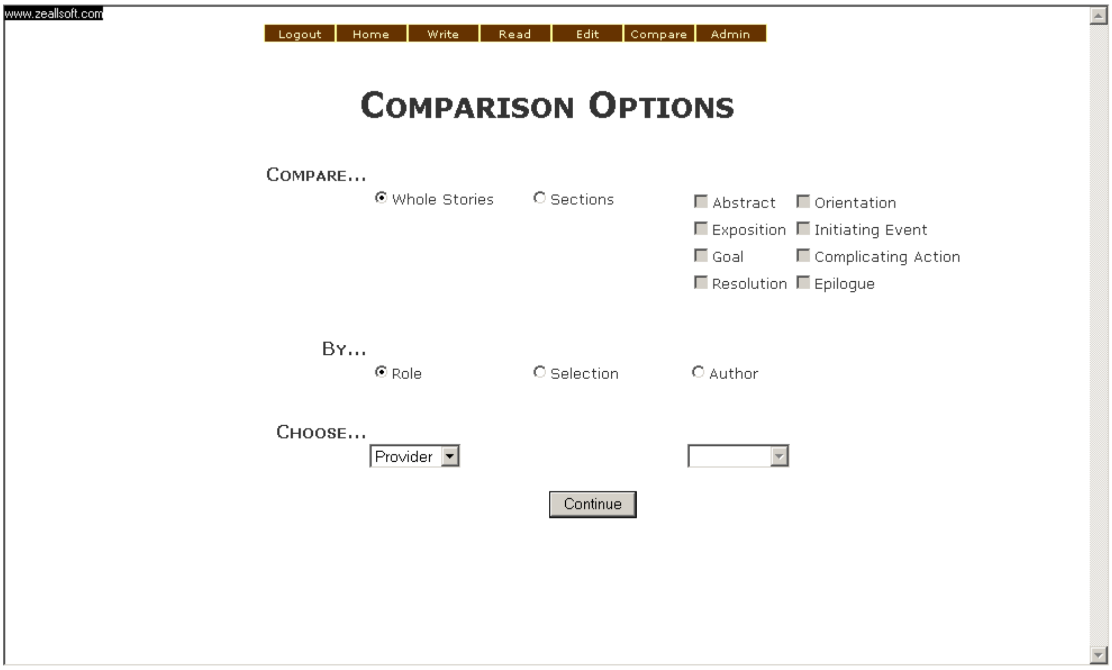


FRONT PAGE FOR REGISTERED USERS



COMPARE STORIES





READ STORIES

www.realbolt.com

Logout | Home | Write | Read | Edit | Compare | Admin

READ A STORY...

End User_6 (Contact_8)

Read Story

END USER_6

By Contact_8

We tend to regard the innovation pathway as this 5-step process. Now we may have ended up it being only 5 steps because that neatly fitted onto the graphic and everybody could understand it. But it's really going through, and I've got a couple of examples that are within these of assessing someone has a bright idea. Will it work? So the first thing is to see, is this bright idea actually feasible? Now that may be mathematics and theoretical, it may be an experiment in a test tube but it's basically going to be, does the concept stand up? That may well be actually done within a university context by an MSc student or maybe a PhD almost at the university's or a research council's expense, but it's basically, does this bright idea stack up? After that the next step which I think that is still relatively fundamental research which may or may not get oil companies joining in, it may still be a bit early, is ok the idea works, but what are its applications? As an example if it works in air and water will it work in hydrocarbon, liquid and gas? Because obviously they are slightly different just as an example. Again probably bent scale, lab scale, little. If all that looks good and the results look promising and I guess the end result of that phase may be the most amazing wooden box with wires sticking out of it that just proves it works.

The next step of the development phase is then basically, how do we turn that wooden box with all the wires into something that we could actually use in a real live deployment? So that's probably about as much in the design stage. Then probably we'd test it maybe in a factory or maybe on a more representative flow loop, but not necessarily out in the field. But basically now we've made this big version, will it work? Because we've had occasions where there are a variety of different technologies to do with cleaning produced water at the moment. A number of them have required electricity to do various things. They all work in different ways, but what we found is the moment they were scaled up to a pilot stage, the power consumption rose considerably more than just the scale up would have implied, and they've all ended up being extremely high power users. Now, had we got something wrong? I think it was probably in those cases that if take one example that use ultraviolet lights, in a small scale, in a lab the fluid can get very close to the lights. You build a bigger one and you basically have to put more oomph in it in order to get the ultraviolet to get through a much bigger volume of standing water. And so the power consumptions went up astronomically, but we wouldn't have known that unless we'd done it.

And then the final step, field-testing, is obviously where you take it out and use it in anger to see if it works, and probably again that would not be just plug it in and see what happens. We'd probably set up in advance a test matrix of things to vary that might happen when... Because we can only test it in one place, but what we're trying to look is for its suitability for deployment in a number of different applications. So if it's off the main line, if you have the opportunity to fiddle and play and see what its capabilities and limitations are, then that is the time to use it. Now obviously I've been talking there more about hardware and bits of kit, but actually it also does relate to software as well. We've stopped calling it software because software to most people means big mass produced multiple packages like Word and Microsoft or games or whatever, so we actually refer to it as computer code. Within the research centre here, as well as paying others to do research we do do our own. We've got a load of applied mathematicians and geoscientists who are basically manipulating seismic data sets, reservoir models etc, which are of course large data volumes. What we want to be able to do is to not simply manipulate those large data volumes, but do clever things with them.

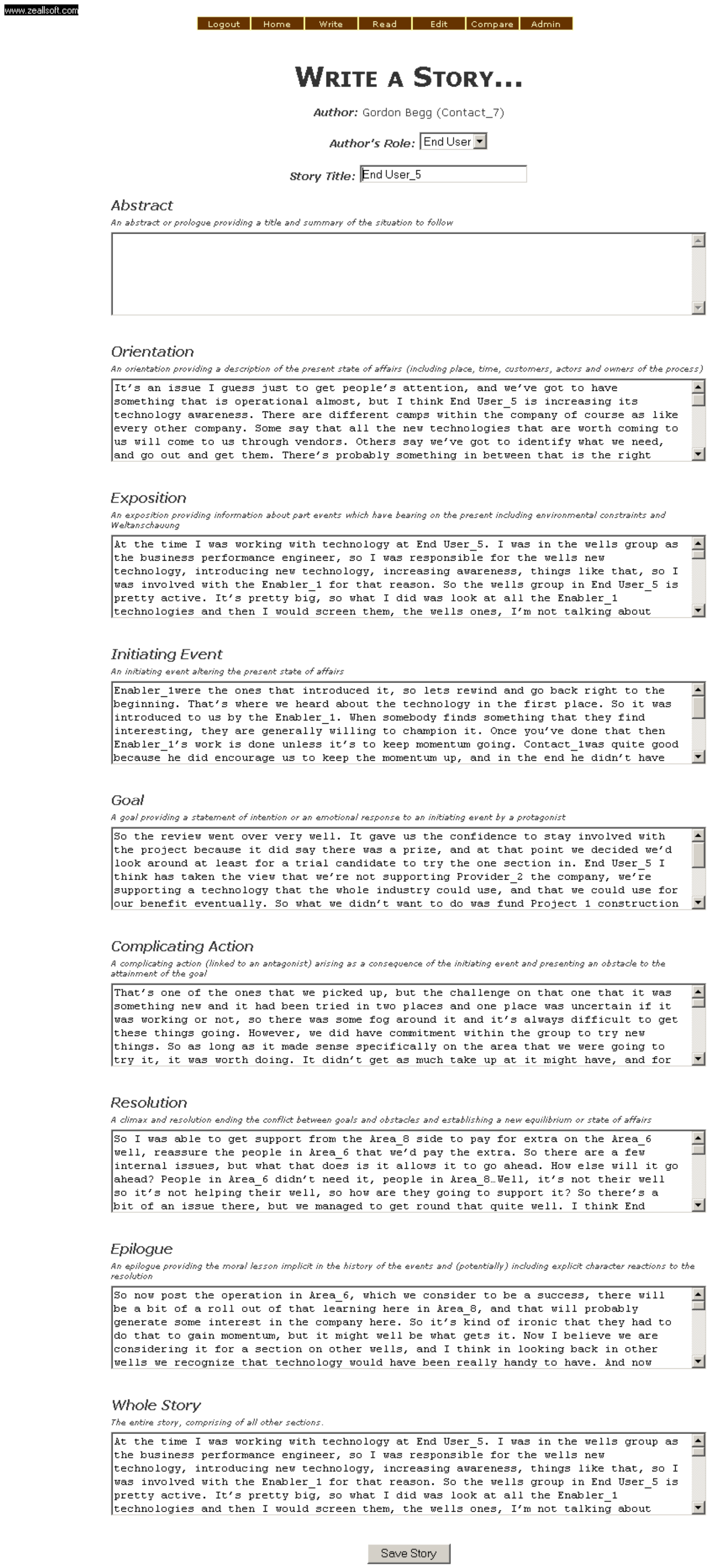
So I've got a couple of examples. This is just basically a software example which shows where I reckon that these things fit in and then the other one is a hardware example, this Enabler_1 know about, is a company called Provider_1.

That is actually software code for multi-face flow modeling, that is not an Enabler_1 project but it's a very big UK project that has received a lot of money from the Research Councils so that is sort of what we've got in there.

A large number of Enabler_1 member companies are participating in this project, but is also received approximately 50% Government funding. It's called Project_12. It's operated by University_1 but it is also a collaboration between two departments in University_1 Chemical and Mechanical Engineering, University_2, University_4 Applied Mathematicians and University_3. it's a big, big project.

Basically it's a typical example of experimental work attempting to build models and then to construct models into code that can be solved in a relatively timely fashion. As an example, one of the initial bits of code that was written ran slower than the real time it was modeling, which of course if you're actually trying to model what is going to happen in a period of time, you'd actually like to get that model to run faster than it actually happens. So the applied mathematicians have actually been in there basically reconstructing the algorithms for optimal solution. They've also been doing clever stuff on what they call adaptive gridding such as where you've got changes happening very rapidly, you analyse it in very small chunks but when a change takes a relatively long time or relatively long distance along the pipe, then they

WRITE A STORY



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Logout | Home | Write | Read | Edit | Compare | Admin

WRITE A STORY...

Author: Gordon Begg (Contact_7)

Author's Role: End User

Story Title: End User_5

Abstract

An abstract or prologue providing a title and summary of the situation to follow

Orientation

An orientation providing a description of the present state of affairs (including place, time, customers, actors and owners of the process)

It's an issue I guess just to get people's attention, and we've got to have something that is operational almost, but I think End User_5 is increasing its technology awareness. There are different camps within the company of course as like every other company. Some say that all the new technologies that are worth coming to us will come to us through vendors. Others say we've got to identify what we need, and go out and get them. There's probably something in between that is the right

Exposition

An exposition providing information about part events which have bearing on the present including environmental constraints and Weltanschauung

At the time I was working with technology at End User_5. I was in the wells group as the business performance engineer, so I was responsible for the wells new technology, introducing new technology, increasing awareness, things like that, so I was involved with the Enabler_1 for that reason. So the wells group in End User_5 is pretty active. It's pretty big, so what I did was look at all the Enabler_1 technologies and then I would screen them, the wells ones, I'm not talking about

Initiating Event

An initiating event altering the present state of affairs

Enabler_1were the ones that introduced it, so lets rewind and go back right to the beginning. That's where we heard about the technology in the first place. So it was introduced to us by the Enabler_1. When somebody finds something that they find interesting, they are generally willing to champion it. Once you've done that then Enabler_1's work is done unless it's to keep momentum going. Contact_1was quite good because he did encourage us to keep the momentum up, and in the end he didn't have

Goal

A goal providing a statement of intention or an emotional response to an initiating event by a protagonist

So the review went over very well. It gave us the confidence to stay involved with the project because it did say there was a prize, and at that point we decided we'd look around at least for a trial candidate to try the one section in. End User_5 I think has taken the view that we're not supporting Provider_2 the company, we're supporting a technology that the whole industry could use, and that we could use for our benefit eventually. So what we didn't want to do was fund Project 1 construction

Complicating Action

A complicating action (linked to an antagonist) arising as a consequence of the initiating event and presenting an obstacle to the attainment of the goal

That's one of the ones that we picked up, but the challenge on that one that it was something new and it had been tried in two places and one place was uncertain if it was working or not, so there was some fog around it and it's always difficult to get these things going. However, we did have commitment within the group to try new things. So as long as it made sense specifically on the area that we were going to try it, it was worth doing. It didn't get as much take up at it might have, and for

Resolution

A climax and resolution ending the conflict between goals and obstacles and establishing a new equilibrium or state of affairs

So I was able to get support from the Area_8 side to pay for extra on the Area_6 well, reassure the people in Area_6 that we'd pay the extra. So there are a few internal issues, but what that does is it allows it to go ahead. How else will it go ahead? People in Area_6 didn't need it, people in Area_8…Well, it's not their well so it's not helping their well, so how are they going to support it? So there's a bit of an issue there, but we managed to get round that quite well. I think End

Epilogue

An epilogue providing the moral lesson implicit in the history of the events and (potentially) including explicit character reactions to the resolution

So now post the operation in Area_6, which we consider to be a success, there will be a bit of a roll out of that learning here in Area_8, and that will probably generate some interest in the company here. So it's kind of ironic that they had to do that to gain momentum, but it might well be what gets it. Now I believe we are considering it for a section on other wells, and I think in looking back in other wells we recognize that technology would have been really handy to have. And now

Whole Story

The entire story, comprising of all other sections.

At the time I was working with technology at End User_5. I was in the wells group as the business performance engineer, so I was responsible for the wells new technology, introducing new technology, increasing awareness, things like that, so I was involved with the Enabler_1 for that reason. So the wells group in End User_5 is pretty active. It's pretty big, so what I did was look at all the Enabler_1 technologies and then I would screen them, the wells ones, I'm not talking about

Save Story

APPENDIX IV: Contextual Framework

‘Oil is like a wild animal. Whoever captures it has it.’ (J. Paul Getty)

1 Introduction

The aim of this appendix is to present a contextual framework for the research. Traditionally, there are a number of purposes in providing a contextual framework. Marshall and Rossman (1999, p. 23) suggest that these are ‘(a) to describe the substantive focus of the research – the topic and its purpose; (b) to frame it in larger theoretical, policy, social, or practical domains and thereby develop its significance; (c) to pose initial research questions; (d) to forecast the literature to be discussed in the review of the related literature; and (e) to discuss the limitations of the study.’

In this instance the purpose in providing a contextual framework for the research is three-fold. Firstly, to explain generally the importance of the oil and gas industry within a global context, by showing its pivotal role in the development of developed (and developing economies). Secondly, the appendix aims to go some way towards illustrating the highly complex nature of the industry in general, and the political, economic and environmental issues which have affected its development over the last 150 years. Thirdly, from a more localised perspective the appendix also illustrates the importance of technological innovation within this industry in the United Kingdom Continental Shelf (UKCS).

The appendix is divided into two sections: the first addresses the history of the UK oil and gas industry within a global context from its formation in the late 19th century, to the discovery of oil and gas in the North Sea in the late 1960s. It shows how developments in the exploitation of oil and gas lead from an environment with little or no legal, political or infrastructural support, to the formalisation of a cohesive global industry. It illustrates the importance which the oil and gas industry has had (and continues to have) on the British economy and other world economies, and the close relationship between the industry and government policy. Importantly, it outlines the complex economic, political and environmental factors which have had bearing on the development of the UKCS, and their concomitant technological requirements for the exploration and production within that sector.

The second section provides an outline of the current situation in the UK oil and gas industry. The section shows the economic importance of the industry to the British economy, and explains the importance of the role which (technological) innovation currently plays within the UKCS. It also specifically identifies key players who have been involved within this process, as well as those players who are currently involved.

2 History of the Industry

2.1 Formalisation of an Industry

Oil and gas have been used for thousands of years by different cultures including the Egyptians, Greeks and Persians for a myriad of different purposes including natural gas being used as a source of lighting in China as far back as 200BC (Dott, 1969; Shah, 2004). As Hamilton (1986, p.10) states: ‘Natural seepages of oil, in pools, from shale and from tar sands, have been known since time immemorial and used from the earliest civilizations onward to provide bitumen for building, pitch for ships, glues for toys and unguents for arthritis, back pain and other ailments.’

The contribution of oil to society as a natural source of energy was however was however largely overlooked until the middle of the nineteenth century. During the 18th and 19th Centuries, whale oil provided a key source of illuminating fuel and lubricant. However, whalers were unable to cater for the growing demand. This coupled with the associated decline in whale numbers lead to the need to find other more sustainable sources of oil. It was in 1859, when ‘Colonel’ Drake discovered and subsequently sold crude oil as a lighting fuel at Titusville in Pennsylvania, that oil became arguably the most important of all natural resources. Although commonly attributed to Drake, the world’s first commercial oil well was brought into production in 1858 in Oil Springs, Ontario. Nevertheless, from these modest beginnings in the mid nineteenth century until the beginning of the twentieth century, oil was not seen as being especially commercially important in relation to other, more readily available sources of energy. Consequently of course this also meant that the oil industry itself was not seen as important to national economies.

During the 19th Century, and indeed after 1900, oil's main application was as a source of illumination and lubricant, with oil being used as lamp fuel, candles and grease in both domestic and commercial settings. In fact until the 1880s, the oil industry was a subset of the coal industry, with the principle source of kerosene being coal or asphalt rather than crude oil.

Originally used as an alternative source of fuel for lighting, oil's inherent value was only realised following the invention of the internal combustion engine at the end of the nineteenth century. Its role (or one of its many derivatives) as a fuel for almost all current forms of transport has catalysed the development of both industries and national economies. As a consequence, the establishment of national industries was of paramount importance, as can be seen by the controlling interest taken in Anglo-Persian oil by the British government in 1913, making it the first 'major British firm in which the state took a controlling interest' (Woolfson et al, 1996, p.4). However, as Hall and Atkinson (1983, p.26) state: 'Initially the industry was characterised by many small producers but a general condition of excess supply and falling prices allowed a single company to attain a dominant position.'

At the beginning of the twentieth century, a number of obstacles stood in the way of developing national oil industries. Arguably the principle reason was the cost of transporting the oil. Standard Oil, Rockefeller's American oil giant, was able to secure a monopoly over the American market by controlling transport. However, America had access to onshore domestic sources of oil, unlike Britain, which at the turn of the century was importing its oil from the Middle East.

The oil industry's ability to act as an economic catalyst is apparent from the development of the railways which it stimulated in order to have access to an effective transportation system. Standard Oil was able to capitalise on its size and strengthen its position by negotiating discounts for the large volumes of oil transported, and went so far as to negotiate penalties with the railways to be applied to its competitors (Philip, 1994; Yeomans, 2004). Shipping oil overseas also incurred huge costs which challenged its economic viability. For example, in 1863, the cost of transporting crude oil from Ontario (Canada) to Hamburg (Germany) was over eight times the cost of the refined oil (Melamid, 1991, p.97 Cited in: Philip, 1994, p.24). The investment from the oil companies in transportation was not limited to publicly available forms alone. Although requiring substantial initial investment, they preferred to develop purpose-built transportation systems in the form of oil pipelines. This helped to strengthen the companies' competitive advantage by extending their control of operations, as well as effectively helping to formalise the industry by moving towards a more corporate structure.

The division of the Standard Oil Trust in 1911 lead to the establishment of three of the most significant companies in the industry during the 20th century: Socal; Mobil and Exxon; who along with Gulf, Texaco, Shell and BP formed 'The Seven Sisters' – the companies which in effect controlled the industry during the 20th century (Roberts, 2004). The seven large oil companies (three of which - Esso, Mobil and Chevron - were descended from Standard Oil) were able to consolidate their position by having a strategic involvement in all stages of the industry - from the initial stages of recovery from reserves through to refining and marketing. Their ability to exert control over all these stages of the production chain enabled them to survive for long periods of low oil prices (evident in the mid eighties and again in the nineties) by focussing on different parts of the chain according to circumstances, and therefore effectively control the supply and demand of oil: 'It is this that gives the big firms their periodic ability to influence price and consequently transform the oil trade into a source of superprofit' (Woolfson et al, 1996).

Besides establishing a corporate structure, the oil industry was also becoming a truly international concern. Although the USA and Russia had domestic reserves as well as domestic markets, the need to control production in areas such as the Dutch East Indies, and the Middle East resulted in a struggle to monopolise control. Britain's interests in Persia, represented by Anglo-Persian were bolstered by investment in the company by the British government (Yeomans, 2004).

Although the relationship between government and industry was well established early in the history of the industry, it was not until the 1930s that governments took an active role in actually shaping the industry. 1938 saw Mexico nationalise all its oil companies in an effort to improve conditions for its field workers. 1943 saw Venezuela start an initiative which would eventually lead to a 50-50 profit sharing agreement, a system which was also to be adopted in 1951 by Saudi Arabia, Iraq and Kuwait. This was to be a significant change for both companies and countries, as it meant that the countries profited not only from rises in production but from rises in oil prices directly.

Year	Coal	Lignite	Oil	Natural Gas	Water Power
1860	88	1	negl.	-	1
1870	136	3	1	-	1
1880	209	5	4	-	1
1890	316	8	9	3	1
1900	467	15	18	6	1
1910	704	23	39	14	3

Table 23: Growth in world commercial energy production, 1860 – 1910 (million tons of oil equivalent) [Source: Derived from Jenkins, 1986 (cited in: Philip, 1994, p.23)]

2.2 The British Situation

The relationship between British economic development and the establishment of a British oil and gas industry began in the nineteenth century. At the beginning of the twentieth century, oil was important to Great Britain strategically rather than economically due to the need to fuel its navy, one of the key functions of which was to protect traditional trade routes. The British Navy preferred to use oil as it was more reliable than coal (and also cleaner), despite being more expensive initially (Philip, 1994; Yeomans, 2004). As was mentioned previously, the key change in the importance of oil was in the development of the internal combustion engine. Although there were more cars powered by steam and electricity than petroleum in the USA in 1900 (Philip, 1994, p.28), the mass production of Henry Ford's Model T in 1908 triggered a revolution in machinery using petroleum as fuel, and consequently a dramatic increase in the rate of oil consumption.

In effect, the value of oil was in its ability to protect the supply of other commodities, rather than as a commodity in its own right (Yeomans, 2004). Its growth in economic importance was slow, with domestically produced coal supplying the majority of the energy needs of Great Britain at the beginning of the century, rather than the oil imported from the Middle East. However, by 1920, petroleum made up 5% of the value of British imports and 2% of re-exports, compared to 1.4% of imports and 1.6% of re-exports in 1913.

The importance of the industry to the British economy continued to grow, and by 1938 the international trading profits of Anglo-Persian Oil (which later became BP), Royal Dutch Shell (the Anglo-Dutch conglomerate resulting from the take-over of Marcus Samuel's Shell by

Royal Dutch Oil) and Burmah Oil (the only other British oil company at that time) represented almost 4% of the profit income of UK manufacturing firms.

Britain's position as a key player in the world oil industry was unparalleled. Not only did Britain control the key sources of the oil in the form of its colonies (which were added to again in the Middle East in the form of Turkey after the First World War), but was also able to control the markets in the form of its own dependent territories. Strategic alliances and cartel agreements (which were to set a precedent for industry relationships to the present day) further strengthened the position of Britain's oil companies by attempting to regulate the market, with the result that during the mid to late twenties and thirties, Shell and Anglo-Persian were provided with dividends of 20-25% annually.

The increasing economic importance of the industry meant that the relationships between the oil companies and the British government were also becoming increasingly strong. In 1914, the British government took a 51% share in Anglo-Persian, ensuring that it had the financial backing to become a serious financial venture with a long-term future (Shah, 2004; Philip, 1994). In addition, Anglo-Persian was awarded the contract to supply the British Navy with fuel oil.

When war broke out in 1914, it was not perhaps initially anticipated the vital role that oil would play. With the Royal Navy now converted almost entirely from using coal as its main source of fuel to oil, the use of 60,000 trucks by the British army, and the establishment of the Royal Air Force, oil can be seen to have played a vital role in mobilising the British armed forces, and consequently aided greatly in winning the war. So much so in fact, that Lord Curzon stated that the Allies 'floated to victory on a wave of oil.' (Hamilton, 1986)

The relationship between oil and war was observed during the First World War by Ross amongst others: 'In the greatest of wars…we read of armies striking at or tenaciously defending territories for the main reason that petroleum abounds therein' (Ross, 1917, p.1). World War 1 was arguably the first large scale conflict which saw countries targeting areas for acquisition (both during the conflict and in the settlements thereafter) largely based on their natural resources, a key one of which was oil.

2.3 Between the Wars

Having consolidated its position in the Middle East following the appropriation of Turkey's colonial possessions, Britain further extended its political control of the oil industry in the region by the establishment of Mesopotamia (Iraq) as a British protectorate, and the establishment of Saudi Arabia as a client state. In fact, the impact of Britain's positioning gave it 'political control over the bulk of known oil reserves in the eastern hemisphere (outside the USSR)' (Woolfson et al, 1996, p.8). Although the American oil companies (such as Texaco and Socal) were buying up concessions in Saudi Arabia (at a time when Saudi Arabia had no known reserves), Britain's position in the Middle East was unchallenged. Economically, this market was important for Britain for a number of reasons: most obviously, the scale of the market strengthened Britain's position as a leading producer; the oil was cheaper to produce; and the position of the reserves in relation to Europe meant that transportation costs were relatively low.

Year	**Middle East**	**USA**	**Venezuela**	**Far East**
1950	0.13	1.18	0.30	0.70
1951	0.11	1.32	0.37	0.75
1952	0.17	1.58	0.42	0.88
1953	0.11	1.69	0.39	0.83
1954	0.11	1.86	0.39	0.83
1955	0.12	1.88	0.41	0.86

Table 24: Unit costs of maintaining and expanding production of crude oil, by area, 1950-55 (US dollars per barrel) [Source: Issawi and Yeganeh, 1962, p.54. (Cited in: Philip, 1994, p.104)]

By the Nineteen Thirties, Shell and Anglo-Persian held an important position within the British economy. They were among the largest companies in Britain, and combined with the collapse in exports, their importance was made even greater: 'For British capital, its two great oil companies represented the future. They were large, integrated and internationally organized. They brought together the control of natural resources, high technology and sophisticated product markets. Most important of all, they could match on a global scale the largest of American companies.' (Woolfson et al, 1996, p.9)

Along with Mobil, Chevron, Texaco, Gulf and Exxon (the five largest American oil companies), Shell and Anglo-Persian controlled over 60% of the world's 'commercially marketed refined oil products' (Woolfson et al, 1996), a position that was to remain unchanged for the rest of the twentieth century. In fact, it became apparent that oil was not only an important source of energy, but a vital force for the economic and social development of nations. (Shah, 2004; Yeomans, 2004)

2.4 The Effect of World War Two on the International Oil Industry

By 1939, the oil consumption of the United Kingdom had reached 242,000 barrels per day (See Table 22). The scale of this consumption indicates a change in the importance of oil: not only was it an important strategic asset, but also as a valuable commodity in its own right. Britain (through Shell and Anglo-Persian) was able to compete with the USA.

Country	**Consumption (thousand b/d)**
USA	3,384
USSR, Eastern Europe and China (combined)	540
Latin America and Caribbean	345
Asia (total)	257
United Kingdom	242
Germany	148
Canada	139
France	124
Rest of Western Europe	217
World	**5,534**

Table 25: Oil consumption of selected countries: 1939 [Source: Philip, 1994, p.38)]

However, the advent of the Second World War affected this position of strength which had been developed by Britain. Having benefited substantially from the settlement of World War I, the British government found this situation almost reversed at the end of World War II. The relationship between oil and military and economic power was well understood: both Axis and Allied countries had identified the acquisition and/or control of oil supplies as part of their objectives of war. Germany and Japan identified the acquisition of natural resources (including oil reserves) as neither had access within their own territories. America had specific objectives relating to oil: 'These included the elimination of protectionist tariff blocks (of which the biggest was the sterling area) and the end of any restriction on access to the development of resources, of which the most valuable were the oil reserves within the British Empire and its protectorates' (Woolfson et al, 1996, p.9).

Because of Britain's dependence on American financial and military support, Britain was forced to agree to America's terms. At the end of the Second World War, Britain's position of dominance in the Middle East was eroded due to its poor bargaining position with the USA. Because of Britain's dependence on the USA for economic support, Britain was forced to concede an end to the restriction on access to the development of resources, which were principally in areas within the British Empire. America was able to further strengthen its position by establishing Saudi Arabia as a major oil producing country, where America held a vast number of concessions.

After World War Two, the value of oil as a diplomatic bargaining tool became apparent: 'Oil was now used to achieve the diplomatic objectives of the Cold War, and in doing so brought a still greater interlocking between oil companies and government' (Woolfson et al, 1996, p.10). America established two aid programmes intended to assist economic development in both Europe and Japan. Both the economic and political systems of Europe were badly damaged by the war, and a programme of recovery was required to stabilise the region, and provide a foundation for economic development. The European aid programme (The Marshall Plan) channelled around $13,000 million to 16 European countries (Austria, Belgium, Denmark, France, Greece, Great Britain, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Sweden, Switzerland and Turkey), resulting in an aggregate gross national product rise of more than 30%, as well as an increase in industrial production of 40% over pre-war levels by 1952 (Hug, 2005). A key element of the Plan was the supply of cheap energy to Europe. By the middle of 1951, America had provided $1,567 million to finance fuel imports (Hogan, 2005) into Europe. The fuel, in the form of oil, was provided at significantly lower prices than the 1930s, and was exported by Aramco (a consortium of American oil majors comprising Esso, Chevron, Mobil, Socal and Texaco) from Saudi Arabia. In addition, America built an oil pipeline to supplement the oil tankers to transport the oil more effectively.

In relation to the oil industry, The Marshall Plan had far reaching effects. In return for providing oil at a reduced cost to Europe, the American oil majors were guaranteed a protected market inside the USA which sustained pre-war prices. In addition, The Plan benefited the oil companies by making the participating countries reliant on oil (rather than coal) as their primary source of fuel, which was provided from (largely) U.S. controlled reserves in the Middle East.

2.5 After the War

The complex relationship with the USA added to the confusion of the global market. Although a direct competitor for the control of oil reserves, Britain was forced to rely on American military supremacy to safeguard their interests in the Middle East and elsewhere. This situation was to change radically however, when both oil and gas were discovered in the North Sea in the late Nineteen Sixties.

In Britain, oil was becoming increasingly important economically. By 1953, the profits of the British oil companies made up 14% of the total profit of all UK industrial companies (Woolfson et al, 1996, p.12). Britain in the 1950s also experienced a boom in private motoring, strengthening the position of the oil companies still further. British oil companies increased their volume of sales as a measure to compensate the low price of oil, and focussed their attention on developing other regions. Kuwait became another key oil producing country in the Middle East, along side Iran and Iraq, while Nigeria, Brunei and Borneo were also added to this growing British portfolio.

There was also an additional factor which impacted greatly in the development on the British oil and gas industry – the formation of the Organization of the Petroleum Exporting Countries (OPEC). The 1950s saw the supremacy of the major oil companies being challenged. ‘This took the form of a growth in the number and activity of small independent oil companies as well as an increase in exports from the USSR and Libya’ (Hall and Atkinson, 1983, p.27). Because of this unchecked influx of oil into an already saturated market, the oil majors had no choice but to reduce oil prices if they wished to retain their market shares.

In response to this, the producing countries, which now had an established interest in the price of oil, formed OPEC in 1960 in order to prevent future price reductions. However, although OPEC successfully prevented any future price reductions, it was unable to increase oil prices due principally to Iran’s refusal to limit its own production. 1970 saw a left wing government in power in Libya which immediately reduced its own output while increasing the price of oil. Other OPEC countries quickly followed suite, and the early 1970s saw a shift in dominance of the world oil market to the OPEC countries, who implemented a series of small price increases culminating in a large increase in price ($2.8 to $11.6 per barrel) in 1973-74. Prior to the 1970s the industry suffered from constant over supply through the discovery and subsequent development in regions such as Iran, Mexico and Venezuela. There was no reason why any country should not produce as much oil as it possibly could, due to the payment system in effect: 'The system of payment to the producing countries, which linked the total payment to production rather than revenue, created the incentive for each individual producing country to maximise its output. This allowed the oil majors steadily to reduce the real price of oil. If an individual country tried to stand against this trend, then the majors could still meet the overall demand from other sources, in particular from the USA oil reserves' (Hall and Atkinson, 1983, pp.26-27).

2.6 North Sea Oil

Although the change in the balance of power stated above saw a shift away from the oil majors to the producing countries, it was however a significant period for the development of North Sea oil, despite the fact that at the oil prices at the time any discovery would only have been marginally profitable. From 1964 to 1967, the rate of exploration in the UK sector of the North Sea rose steadily. It remained relatively stable until 1970 when the number of exploration wells drills halved from 44 to 22, despite a third round of exploration licenses being issued by the government. The allocation of licenses by the British Government has been a controversial issue. The government had two aims: firstly, to favour allocations towards British companies, and secondly to ensure a rapid rate of exploitation (Jones, 1981). Although arguably it failed in its first aim, the actual rate of production was extremely high, rising from only 5,000 barrels per day in 1970, to around 1,660,000 barrels by 1980 (BP, 2000)

Hall and Atkinson (1983, p.29) state that: 'The oil companies were in fact largely continuing their exploration at this time because of their intense need to diversify their interests and production potential outside the OPEC countries rather than because they saw a large potential in the North Sea'. So rather than the UKCS being seen as an obvious source of oil and gas which was readily accessible to the oil companies, the decision to explore and produce within this environment can be seen to be highly political in nature. This sentiment is further echoed by Woolfson et al (1996, p.15) who suggest that: 'The discovery of North Sea oil in 1969 was not, therefore, accidental. It was a product of the strategic planning required by the geopolitical character of the oil industry.'

However this situation was to change suddenly due to two significant factors. The discovery of major oil fields in the North Sea established the sector as a real commercial opportunity for oil companies. In November 1970 the Forties field was discovered and then in July 1971 the Brent field was found. The other significant factor was the sudden increase in the world oil price which meant that even relatively small fields became serious commercial opportunities. The combination of these factors lead to a dramatic increase in the exploration activity in the mid 1970s. Exploration wells drills rose from 42 in 1973 to 67 in 1974, to a peak of 79 in 1975.

Despite this the number of wells drilled fell to 37 in 1978. Hall and Atkinson suggest two reasons for this: firstly, the change in tax structure over this period which lead to a decrease in the profitability of exploration and secondly the ‘uneven pattern of licensing’ generated by successive governments: ‘This long term shift in bargaining power and control from the oil companies to the producing countries was important for the development of North Sea oil. It explains why the oil companies were eager to develop the North Sea, despite the fact that even substantial oil finds would only have been marginally profitable at 1970 oil prices, and that the oil companies held no great hope or expectation of making such finds’ (Hall and Atkinson, 1983, p.28)

The discovery and extraction of oil from the North Sea was intimately related to the economic strategy of the industry itself, as well as the energy policies of the oil (and gas) producing countries. Several small finds of gas had been made onshore following World War I in Yorkshire, near Edinburgh and near Nottingham. As early as the beginning of World War II, it was looking likely that there was a significant number of small, geographically dispirit oil and gas fields (Hall and Atkinson, 1983). These small discoveries continued after the War with a series of small finds being made in the Midlands, and in the 1950s with larger finds being made in Dorset and Lincolnshire. By the early 1960s, onshore production (of oil) was somewhere around 1,500 barrels per day (approximately 1-2% of total UK oil requirements at the time). Although oil was not discovered (offshore) until 1969, the discovery of major gas finds (Woolfson et al, 1996, p.16) in northern Holland in the late 1950s (the large Groningen gas field) had already pointed to its discovery. Hamilton notes that: ‘geological theory pointed to the offshore as essentially an extension of onshore geology.' (Hamilton, 1986, pp.144-145). This was extremely significant for UK oil and gas interests in the North Sea. Not only did it mean that the oil companies were closely scrutinising the area between the Midlands and the Groningen field in Holland, but that the area between Scotland and Norway was unlikely to be a future source of oil or gas due to the granite rock and water depths requiring more advanced production technology than was available at the time.

In late 1965, the BP jack-up drilling rig Sea Gem discovered gas in the West Sole field in the Southern North Sea, and the gas was brought ashore in 1967. This was quickly followed by the discovery of the giant Forties field in the northern North Sea in 1970 (240 million tonnes of oil), the Brent Field in 1971 (229 tonnes of oil) with the first oil brought ashore from the Argyll Field in 1975. Naturally enough these discoveries, combined with the increase in the world oil price in 1973/74 lead to an explosion in exploration in the North Sea.

It is important to appreciate the significance of these discoveries to the development of the British oil and gas industry, as well the British economy. ‘The discovery of oil altered the entire political environment of the North Sea countries. As long as it was only gas that was found, the question was one of how best to develop the resource and where to find the money to build the pipelines and the processing plants to take the fuel to market. Oil was quite different. It promised far more fundamental changes in the economies of the oil-rich countries, a far greater impact on the local communities nearest the finds and, of course, far greater potential rewards for the companies themselves.’ (Hamilton, 1986, pp.146-7)

The discovery of oil in the North Sea changed the relationships of both the British government and the British oil companies. Until that time, the British oil companies had been heavily reliant on the British government (who had in turn been reliant on the American government) to provide them with both military and diplomatic support. This was essential in order to sustain relationships with the regimes of the less developed countries in the Commonwealth (and elsewhere) that provided the oil.

The exploration and production costs per barrel for the UKCS in 1969 were so high as to make recovery virtually uneconomical: the technology being developed for deep-sea drilling was still in its infancy and the capital costs were huge. However this situation was to suddenly change. The 1944 Bretton Woods agreement, which was arranged in order to ensure a structured approach to economic redevelopment after World War Two, established the American dollar as the world reserve currency, linked all other currencies to the dollar, and established a constant price of gold of $35 per ounce.

	Number of wells drilled each year		
	Exploration	**Appraisal**	**Development**
1964	1	0	0
1965	10	0	0
1966	20	8	3
1967	42	16	13
1968	31	8	36
1969	44	8	27
1970	22	2	28
1971	24	4	34
1972	33	8	36
1973	42	19	21
1974	67	33	20
1975	78	37	21
1976	58	28	54
1977	67	38	96
1978	37	25	96
1979	33	15	102
1980	32	22	122
1981	48	26	137
1982	68	43	118
1983	77	51	96
1984	106	76	108

Table 26: UK offshore drilling activity (1964-1984) [Source: Hann (1986, p.8)]

The British government aimed to use the agreement as a mechanism to re-establish the role of the City of London as a centre of world finance. However in order to do that, the government would have had to rely on vast American loans. Instead, the government opted for nationalising the transport and energy industries, including the oil and gas industry. When Nixon broke the link between dollar and gold values in 1971, he triggered a devaluation of the US currency. Because oil sales were conducted in dollars, the effect was to increase the dollar price of oil. As a result of this, oil prices reached a point where recovery of oil from the North Sea became economical, despite the high recovery costs. However, because of the pressure to recover oil at a rate whereby it would affect global markets, the investment required was immense: ‘In 1972 this was conservatively estimated as requiring the equivalent of 20 per cent of the UK's industrial investment for a decade. Such additional funds were quite beyond the resources of either the British government or the City of London, and were only conceivable as a result of long-term strategic alliance between British and American capital' (Woolfson et al, 1996, p.17).

The effect of this investment was that the two key British operators, Shell and BP, were able to extract the oil very quickly. Post-war economic policies and the oil market itself drove the need as well as the ability for these companies to be able to extract North Sea oil quickly: 'By mid-1971 the rise in price was sufficient for the oil majors operating in the UKCS to action the development of the two big fields then discovered: Forties and Brent. Even then the risks and costs were very high. If oil was to be extracted on a scale that would impact on world markets with any speed, a massive and tightly bunched investment programme would be needed' (Woolfson et al, 1996, p.17).

It was the discovery of huge oil fields like Brent which led to the rapid development of the North Sea as a serious provider of oil and gas on a global scale. The seventies then represented a boom time for many organisations involved in the extraction of oil and gas from the North Sea. It was also a period which emphasised the complex relationship of the British government to the offshore oil and gas industry.

2.7 Licensing and Technology

Although the process of allocating licenses by the British government in the mid sixties was an attempt to deliberately favour British companies, the need to extract oil on a scale (and within a timescale) which would impact on the global oil market in a significant way required huge amounts of capital investment. Due to the size of the sums of money involved, this required the British government to use American (as well as British) capital, which in turn lead to what Woolfson et al (1996, p.20) term a 'new type of relationship with US capital'.

Changes in the licensing arrangements in the late sixties and earlier seventies altered the balance in favour of foreign companies, and more specifically US companies: 'The licences sold between 1969 and 1972 gave US firms the majority: 54 per cent of the territory as against 32 per cent for the UK firms' (Woolfson, 1996, p.21).

The industry was dominated by US companies, so it was natural given this situation as well as the need to extract the oil and gas as quickly as possible, that a US modus operandi was adopted wholeheartedly: ‘What made the industry unique was the degree to which its production regime was transplanted virtually intact from its American base. This was so for its technology and its management structures, its systems of contract and supply, and even for those areas usually most susceptible to local modification: health and safety practices and industrial relations’ (Woolfson et al, 1996, p.22). This lead to a situation whereby the development of new technologies was dominated by US firms, effectively stifling British entry into the field. Even the establishment of the OETB (Offshore Energy Technology Board) by Tony Benn, the then Energy Minister, in 1975, failed to change this state of affairs. Not only was did the OETB have a limited amount of funding, there was also the perception amongst British companies that the US companies has already developed their technological competence, and that by the time British companies caught up, it would no longer be as lucrative for them.

This period also saw an attempt (by a now Labour) government to become much more closely involved with the process of oil production. In 1975 the government passed the Petroleum and Submarine Pipelines Act in an attempt to bring the industry more under government control. In addition, 1976 saw the creation of the British National Oil Company (BNOC). BNOC was created ‘to take shares (on a commercial basis) in licences, and to trade in oil on behalf of the government’ (Upton, 1996, p.57).

Although this was seen at the time as a move to attempt to nationalise the entire industry, it was in fact not so far reaching, although it was important for securing the role of Britain and British companies in the development of the UKCS. BNOC however was short-lived. The laissez-faire politics of the Thatcherite government in the eighties were at odds with the concept of state control of an industry.

By the 1980s new fields were regularly coming on stream, in addition to the giant oil and gas fields already in place. Production grew from 80 million tonnes a year in 1979 to over 100 in 1982, to over 120 in 1985. Industry optimism was not to last. In 1988 an explosion and fire on the Piper Alpha platform claimed the lives of 167 workers. The Cullen report which was published in 1990 made a large number of recommendations regarding heath and safety issues for the industry. Estimates for the cost of the recommended safety related hardware ran to over £850 million, with many facilities having to suspend production while they were modified, and (at least partially because of this) oil production fell by almost 20% in 1989.

Despite this, by the mid-1990s the industry was again experiencing a boom time. In 1994 sales of oil and gas brought in over £1.5 billion to the Treasury, and made a positive contribution to the UK balance of payments of around £4 billion. By 2008, the industry brought in almost £10 billion to the British Treasury (BERR, 2008).

3 The Current Situation: The Industry in the Knowledge Economy

3.1 Introduction

The oil and gas industry can be seen to be directly important to the British economy for two main reasons: the number of people employed (both directly and indirectly) by the industry, and the contribution to GVA[1], however as well as these well known and understood general economic factors, the industry can also be seen to be important in the development of the new form of global economy identified in the first chapter: the knowledge economy. The industry can be seen to have a number of the characteristics associated with the knowledge economy, although specifically in relation to this research, it can be seen to emphasise the importance of the application of knowledge, the use of ICTs as supporting tools for managing data, information and knowledge-based processes, and the importance of technological innovation.

Although often viewed as an industry in decline, the UK offshore oil and gas industry is arguably only just over half way through its known existing reserves. The UKOOA Economic Report (2005) states that in addition to the 34 billion barrels of oil and gas (boe) which have already been produced from the UKCS, an estimated 28 billion boe still exist. Naturally enough, the industry has focussed on the extraction of oil and gas from readily recoverable fields, and as such much of the remaining reserves are in less accessible areas, such as deep water environments. The development and application of new technologies which will allow companies to explore and develop these fields can be seen to be critical to the survival of the industry.

For over thirty years, the oil and gas industry has provided a significant source of employment, with a recent estimate by the UK Offshore Operators Association (UKOOA) placing UKCS employment at around 260,000. Of this figure, 30,000 are employed directly by Exploration and Production (E&P) companies, as well as 155,000 industry contractors (UKOOA, 2005). The relatively steady decline in staffing in the offshore industry can be seen to be linked to the decline in production. Since the early seventies, the total production of oil and gas (in million tonnes of oil equivalent) can be seen to have risen to a peak around 1999-2000. In 2000, the Scottish Parliament reported that 'net exports of crude oil and natural gas were worth £6 billion. In the same year, the value of UK indigenous crude oil and natural gas production was £23 billion, or 2.7% of GVA.' (Scottish Parliament, 2002). Since then both oil and gas production can be seen to be gradually declining. Despite this gradual decline, by 2004 1.3 billion barrels of oil and gas were produced from the UKCS, enough to provide over 80% of the energy needs of the UK.

3.2 The importance of technology within the UK oil and gas industry

Technology can be seen to have played (and be continuing to play) a vital role within the development and exploration of the UKCS. The rate at which the area was exploited was, to a large extent, dependent on the quality and availability of appropriate technology that had hitherto been unnecessary for inshore production: 'Fortunately, a new generation of technology was either available or under development that would allow production to proceed in the North Sea, a province of the sort that the industry had never before attempted. The whole venture was risky and dangerous - physically and economically. Drilling rigs had to be able to work through water depths much greater than anything tried heretofore, and then still drill another four miles under the seabed. And all the equipment and workers had to cope with a nasty and vicious sea and some of the worst weather in the world' (Yergin, 1991, p.669).

It is wrong to suggest that all forms of technology are equally beneficial to the industry, however Scottish Enterprise (2006) identify three (very broad) types of technologies pertinent to the current and future needs of the sector: finding technologies; production technologies and 'other' technologies. Each of these technology types naturally focuses on different areas of the exploration and production process, and each has its own associated difficulties. The directions in the development of new technologies can be seen to reflect the changing nature and focus of the industry as a whole. For example, Scottish Enterprise states that exploration drilling activity has reduced dramatically over the last few years. This is not necessarily an indicator that the area is running out of oil and gas. Instead SE suggests that the decline is primarily due to economic considerations. Interests in the North Sea as an oil and gas

[1] National Accounts now use GVA (Gross Value Added) as the measure for assessing industry

producing region is reducing generally, and also the capital cost of exploration remains too high. Equally, technologies relating to production are being seen to be improved not only to extract as much oil as possible from available fields, but also due to environmental considerations affecting oil and gas extraction (Scottish Enterprise, 2006).

The importance of new technologies in relation to production is critical, and can be seen to be clarified by BERR in the Digest of United Kingdom Energy Statistics 2005: ‘It can be seen from the production chart that during the 1990s the amount of oil produced from older fields that first started production prior to 1990 has been in decline. Indeed, it is noticeable how even with those fields that started production in the second period 1990 to 1994, a clear steady decline in production volumes is visible during the second half of the 1990s. This is due to the nature of more recent developments where, with the use of new technology, the crude oil can be extracted at a much greater rate than in the past, leading to a much quicker exhaustion of the reserves in that particular field’ (BERR, 2005).

In effect, the use of new technologies is enabling exploration in environments which were previously inaccessible or not financially profitable to pursue, and as a consequence is extending the life of the industry as a whole. One report estimates that between 1990 and 1997: ‘technological advances were responsible for additional reserves of 5.8 billion barrels of oil equivalent (boe) in the UKCS’ (PILOT, 2009). The role of technology within the economic environment outlined above is therefore critical to the financial viability of the UKCS, a point made by Scottish Enterprise (2006, p.10): ‘Reserves are the bedrock of the industry, and with the depletion of their producing fields, the producers must run to stand still. As Operators seek to replace reserves, they must explore in more marginal areas, marginal in terms of technology, geography or commercial possibilities. As this process continues, and the technology develops with it, what was technically and geographically marginal 5 years ago is replaced by new frontiers.’

Specifically, the Innovation and Technology Group (ITG) of the Oil and Gas Industry Task Force (OGITF) identified three potential socio-economic benefits of the development and application of new technologies within the UKCS (DTI, 1999): An additional 5.6 billion boe of reserves made economic; Oil and gas production sustained above 3 million barrels of oil equivalent per day beyond 2010; and The recognition of the UK as a technological innovator with ‘associated export potential to the rest of the world’s oil and gas industry.’

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contribution rather than GDP (Gross Domestic Product)

The first two benefits are more immediate and tangible, and would be achievable in the following ways. Firstly, new technologies could act to reduce exploration and development costs of fields previously considered to be uneconomical; and secondly the application of new technologies could extend the life of existing fields through improved recovery. The last is a potential concomitant benefit which may be associated with the achievement of the first two, and can be seen to be closely related to the role of the industry within the global context of the knowledge economy. The impact on the economy of this potential benefit is not known; however it can be seen to be potentially longer-term and would act to sustain the UK industry by globally exporting knowledge, expertise and technology, rather than the application of these within the localised context of the UKCS. Clearly then, the knowledge and expertise as well as the technological innovations can be seen to be characteristics of the knowledge economy within the industry as a whole. Not only does the short term future of the industry depend on these factors, but also its long term success within a global environment, where this knowledge and expertise, as well as the technologies which have been developed in the North Sea may be applied to other areas across the world.

In short then, there are two aims of applying innovative technologies within the UKCS. In the short-term, to sustain the life of the UKCS as long as is economically viable by reducing exploration, development and recovery costs; and in the longer term, to position the UK oil and gas industry as a competitor within the global industry through its knowledge.

Technology is seen as one of the key methods of addressing a range of factors affecting the upstream oil and gas industry in the UK. However, there is also a perception that it is more than just the application of new technologies that will help to address these issues, but knowledge of the results of its application. ‘Technological innovation is a key factor for competitive success in the upstream oil and gas industry. Not only is it an important means of cutting costs, it also creates possibilities to detect and profitably exploit smaller and less accessibly oil and gas reserves’ (TNO, 1997).

Similarly the Department for Business Enterprise and Regulatory Reform (2008, p.110) further emphasises the relationship between knowledge and the development and application of new technologies: ‘The growing proportion of smaller independent operators working on the UKCS have also stressed the need to pool knowledge and resources and share outcomes. Supporting the development and deployment of new technology will help address the challenges of exploiting more technically difficult and undeveloped areas of the UKCS.’

3.3 Industry Initiatives

Given the importance of technological innovation acknowledged by public and private sector organisations linked to the industry, and more generally of the importance of the industry to the British economy in the short term localised future of the industry, as well as its longer term expansion into a global marketplace, it is perhaps understandable that the industry as a whole has sought to develop a range of (public and/or private sector) initiatives which would seek to prolong the life of the industry, and seek ways for it to develop in a global market place.

Since the discovery of oil in the North Sea, the UK oil and gas industry has been faced with the same problem: the high costs associated with exploration and production in this environment. The degree to which this problem affects this industry is primarily determined by the oil price at the time. The reaction to these fluctuations has led to a range of cost reduction initiatives within the oil companies, contractors and suppliers. However, perhaps more significantly, the reactions (from both the industry and government) to these fluctuations in the prices of oil have also led to initiatives and pan-industry organisations which have sought to ensure that the whole industry (rather than just one organisation) is cost-effective regardless of the oil price. The realisation that co-operative working is more effective is emphasised by these initiatives, for example the need for change in contractual relationships outlined by the Working Group on UKCS Competitiveness.

The roles played by different organisations in developing a strategy for the UK oil and gas industry are numerous. As there are a number of organisations who have all had a part in shaping the future of the industry, there has never been an overarching policy addressing all areas of the industry.

Consequently, the industry has reacted to policy decisions made by (public sector) organisations such as The Department of Energy (in the case of the working group on UKCS competitiveness), The Department of Trade and Industry (now BIS - who supported the development of the OGITF), Scottish Enterprise (who identified energy as one of its target sectors within its Network Strategy), The Offshore Supplies Office (OSO - subsequently IEP), and so on. These organisations have come together at various points to provide input to an industry strategy, but of course each also has its own personal agenda to serve. Some of the most significant recent initiatives are identified below, which can be seen to be pertinent to this research.

3.3.1 The Working Group on UKCS Competitiveness

In 1992, the Minister for Energy, Tim Eggar, established a working group to examine ‘further ways of reducing costs and improving the competitiveness of the UKCS’. The group, formed from industry representatives from both public and private sectors had the following remit:

- to identify and examine proposals for improving the competitiveness of the UK Continental Shelf;
- to consider possible initiatives which could be taken in order to achieve a reduction in capital expenditures and/or operating costs;
- to make recommendations by February 1993 to the President of the Board of Trade and the minister for Energy on action which could be taken by the industry and/or Government.

The group produced 29 recommendations relating to the following areas:

- Operating expenditure (OPEX)
- Safety related Legislation
- Effect of Certification requirements
- Equipment specifications
- Human resources
- Contractual relationships
- Influence of Government policies
- Environmental controls
- New Technology

Although these areas are all equally valid in terms of cost reductions, the last area, ‘New Technology’ is of particular relevance to this research. Specifically, the group produced the following recommendations relating to new technology:

- oil companies should give a high priority to identifying and developing new technology aimed at cost reduction and to assisting its practical application;
- the OETB (Offshore Energy Technology Board) R&D programme should make cost reduction an area of special interest, in close collaboration with the oil industry;
- the Offshore Supplies Office (OSO) should identify specific field developments where cost-reducing technology could be deployed.

A second report was produced outlining some of the key actions taken in light of the Working Group's recommendations. From the actions and progress made in the areas relating to new technology, the emphasis was very much on what the public sector contribution should be to the industry, rather than what the industry could do to help itself. Although the actions appear encouraging, when considering the Working Group's terms of reference (and particularly the last term) and the fact that closer relationships within the industry were seen as essential to the competitive future of the industry, it is surprising to note their public sector focus. In relation to new technology, the report identified the following actions:

Recommendation	**Action Taken**	**Progress Tracking**
Oil companies should give high priority to identifying, developing and applying new technology aimed at cost reduction	OSO survey confirms that cost reduction is a key factor in justification of oil industry r&d projects.	OSO in consultation with industry has identified the areas where new technology is likely to make the greatest impact on cost reduction. OETB will monitor progress, taking action where necessary to maintain progress.
OETB R&D programme should make cost reduction an area of special interest	OETB annual research plan states that development of technology which contributes to cost reduction should be given special consideration. OSO has supported 36 new projects since the Report was published, 23 of which will contribute to cost reduction if successful.	OETB meetings will review progress on the annual research plan. In addition, a target of cost reduction being a consideration in 75% of OSO programme evaluation has been set for 93/94 and 94/95.
OSO should identify specific field developments where cost-reducing technology could be deployed	OSO has been reviewing potential future projects to determine if there are any discoveries which with a traditional approach would be uneconomic but which could be viable with the implementation of cost-reducing technology	Discussions regarding the selected projects will be held with the appropriate oil companies to determine how the technology could be effectively deployed. The potential involvement of a contractor will also be investigated.

Table 27: Actions taken in relation to new technology [Source: DTI (1999)]

3.3.2 Cost Reduction Initiative for the New Era (CRINE)

The CRINE (Cost Reduction Initiative for the New Era) initiative was also first proposed in 1992 with the aim of reducing capital and operating costs for both development and production activities. The industry realised that the 230 ‘small but significant’ oil and gas discoveries (in 1993) were unlikely to be developed due to the economically prohibitive capital and operating costs associated with the area. CRINE had a similar remit to the Working Group on UKCS Competitiveness in that both aimed to increase competitiveness through cost reduction. However, CRINE (which was a private sector initiative set up by UKCS oil company project managers under the auspices of UKOOA) aimed to consider the specific *mechanisms* by which costs could be reduced, whereas the Working Group’s recommendations were (to some extent) more general and more broad. To some extent then, CRINE acted as one of the mechanisms for implementing the recommendations of the Working Group, as can be seen from one of the recommendations of the Working Group relating to the effect of certification requirements:

‘It is concluded that considerable scope exists for securing a reduction in costs. It is recommended that:

(8) a review of quality accreditation systems should be carried out to determine how the economic benefits can be maximised.

(9) there should be industry-wide discussion on ways of reducing documentation and costs consistent with the maintenance of safety and best quality.

(10) these actions should be implemented by CRINE (under the auspices of UKOOA) with OSO providing assistance in co-ordinating any supply side actions, and the outcome should be reviewed by OSO and a report submitted to Ministers within six months.’

(DTI, 1999)

By way of a comparison, CRINE highlighted a study in their report which highlighted the difference in development costs between equivalent projects in the Gulf of Mexico and the North Sea. The study concluded that:

- the estimated total cost of the North Sea topsides was four times that of the Gulf of Mexico equivalent (i.e. £103 million versus £27 million);

- the costs of materials and equipment, for the same duty, were about 70% higher for the North Sea than for the Gulf of Mexico

- the additional costs attributable to the use of operator, as distinct to common industry, standards and specifications, contributed an additional penalty of about 25%, of which approximately one third could be attributed to documentation and the remainder to excessive technical requirements.

Although this is only one example of the different development costs between regions, it clearly highlighted the need for the UK oil and gas industry to reduce costs significantly. The CRINE initiative was driven by the understanding that this change would have to be made at an industry, rather than an organisational level. CRINE was an industry-driven initiative which aimed to change industry practice through cultural change: ‘The quest for cost effective development and the application of new technology has always been part of the culture of the oil and gas industry on the UKCS. This will continue, but the formal adoption by all sectors of the industry of the CRINE philosophy of standardisation, simplification and open communication together with the recommendations of this report, are crucial in producing a dramatic acceleration to this process of change.’ (DTI, 1999)

Briefly, the recommendations of the CRINE report focussed on simplifying the relationships between organisations in supply chains in order to reduce costs. In effect, CRINE aimed to improve the communication mechanisms within the industry, and so consequently improve the supply chain relationships with the effect of reducing costs. By 1996 however, it had become apparent that reducing costs would not be of long term benefit to the UK oil and gas industry, and consequently CRINE extended its remit to actively seeking to making the UK upstream oil and gas industry competitive within a global market place, and in 1997 became the CRINE Network:

‘The objective now is to seek ways of enhancing the value of the services and equipment provided by contractors and suppliers to the operators, not just in field developments but also in field operations. This will extend the commercial life of the UKCS, and through improving the global competitiveness of the supply industry, it will increase export market share to secure employment in this sector well beyond the time when UK becomes a net importer of oil again.’ (DTI, 1999)

The CRINE Network established four workgroups each with remits for improving specific aspects of the industry:

- The Supply Group aimed to create a 'world class supply chain'
- The Wells Group aimed to 'double the value of every well dollar spent'
- The Training and Education Group aimed to ensure that the industry had 'the relevant skills'
- The Benchmarking and Deliverables group aimed to act as a facilitating body

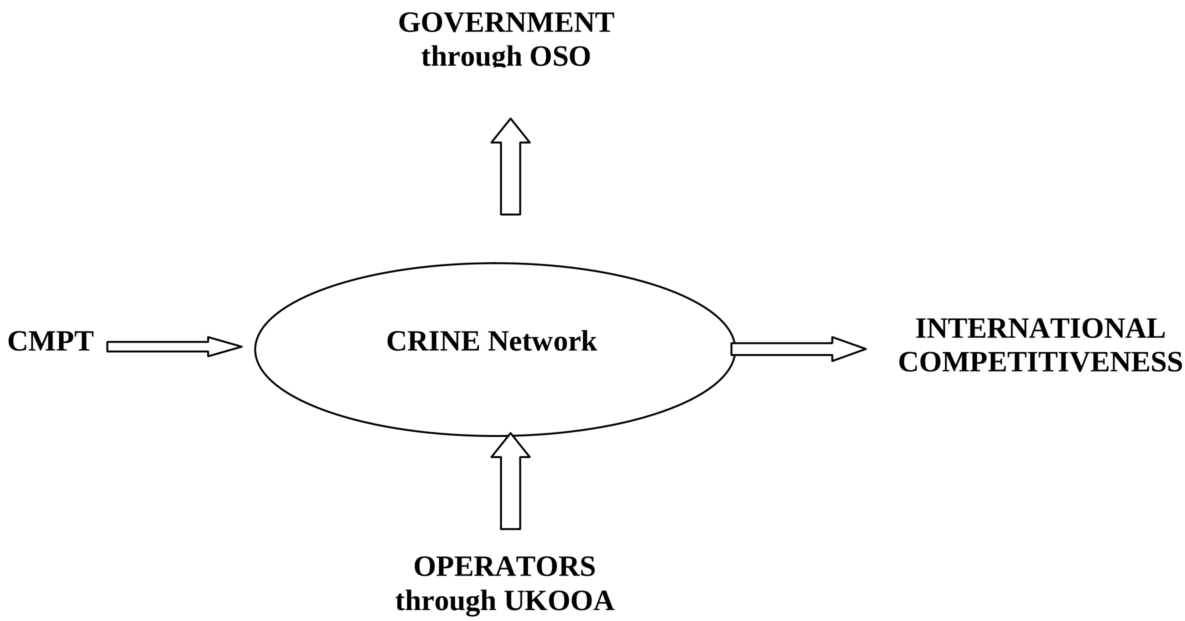

Figure 29: Interactions between the CRINE Network and other industry Bodies [Source: Adapted from DTI (1999)]

In this model, CMPT (The Centre for Marine and Petroleum Technology which shall be discussed later in within this appendix) would act to source, stimulate and promote industry-related research; the government would provide leadership through the Offshore Supplies Office (OSO); and the operators would provide support through UK Offshore Operators Association (UKOOA). As a result of these interactions, it was anticipated that the level of exports would increase, resulting in an increased global market share.

It is important to note two aspects of this model in relation to this research. Firstly, the perceived importance and contribution of research and development to international competitiveness, and consequently the importance of technology brokers and facilitators such as CMPT; and secondly, the importance placed on organisational interaction, rather than organisations working in isolation, in order to achieve international competitiveness of the industry.

The CRINE Network's Supply Chain Management (SCM) Initiative, set up by the Supply Group, was established in order to identify supply chain management improvements specifically to:

- prolong the life of the industry in the North Sea: and
- help to increase the industry's share of the world market

As well as making a number of recommendations at an organisational level (i.e. suggesting areas of improvement for organisations operating within supply chains), the Initiative also made a number of recommendations for 'pan-industry initiatives', including the establishment of a 'Single Industry Body' responsible for improving supply chain management within the industry, and an oil sector extranet.

These (and other) recommendations were forwarded to OGITF - the high level industry initiative established in 1999 to improve the competitiveness of the industry. The CRINE Network was disbanded in September 1999, and many of its functions transferred to the organisations established from the recommendations of OGITF. Functions which transferred to LOGIC (Leading Oil and Gas Industry Competitiveness), the industry body established by OGITF to be responsible for the improvement of supply chain management, were:

- The Principles of CRINE
- The Functional Specifications
- The Best Practice Guidelines
- The Standard Conditions of Contracts
- Wells & Double the Value initiatives
- The Supply Chain Toolkit
- The Supply Chain Methodology
- CRINE Training Programmes

3.3.3 Oil and Gas Industry Task Force (OGITF)

Probably of greatest and most far reaching significance in recent years has been the Oil and Gas Industry Task Force (OGITF) established in 1998: 'The Task Force was established in recognition of the urgent need to reduce the cost base of activity on the UKCS. The Task Force's overall objective was, and continues to be, to create a climate for the UKCS to retain its position as a pre-eminent active centre of oil and gas exploration, development and production and to keep the UK contracting and supplies industry at the leading edge in terms of overall competitiveness' (DTI, 1999)

Due to critical factors such as the mature nature of the UKCS as well as the dramatic fall in oil prices in 1998 (Barker, 1999) to around $12 per barrel, there was an obvious need to produce a strategy to make 'the UK oil and gas sector a modern and competitive industry through collaboration and co-operation.' (DTI, 1999)

The OGITF established seven workgroups to examine specific aspects of the industry:

- Vision Workgroup
- Competitiveness Workgroup
- Fiscal Workgroup
- Regulation and Licensing Workgroup
- Skills and Training Workgroup
- Innovation and Technology Workgroup
- Environmental & Sustainable Development Workgroup

The Workgroups had collectively established proposals for a variety of initiatives and organisations designed to impact quickly on the industry. These lead to the establishment of an organisation to promote best practice throughout the supply chain (LOGIC – Leading Oil & Gas Industry Competitiveness); a website to promote licence trading (LIFT – Licence Initiative for Trading); an interactive map providing an index for UKCS data (DEAL – Digital Energy Atlas & Library); an organisation focusing on training activity and maximising commitment to skills (NTO); a forum to develop a shared understanding of environmental issues related to the offshore industry (NGO – Non-Government Organisation Forum); and pertinent to this research, an organisation to improve the flow of new technology to market (ITF – Industry Technology Facilitator).

In relation to the scope of this research, the work of the innovation and technology group can be seen to be of importance. The Workgroup was made up of over 60 industry representatives consisting of employees from operating and service companies, as well as academics and public sector employees. The aim of the group was to identify and prioritise technologies that ‘could influence the short, medium and long-term future of the UK oil and gas industry’ (DTI, 1999). The Workgroup identified a number of technologies falling into these categories, but also realised that an important factor in brining these technologies to bear would be through a technological leadership strategy: ‘The UK oil and gas industry's high value opportunities span many disciplines and will be realised by no single technology. Therefore, a coherent leadership strategy acknowledges that collaboration within and across the supply and demand sides is key to unlocking much of the remaining value in the UKCS. We believe this strategy is in the best interests of all stakeholders, but will require some change in the channels that link technology demand to supply’ (DTI, 1999, p. 9).

Because of the need for this coherent leadership strategy, the Workgroup also developed a business plan for an ‘Industry Technology Facilitator’ who would occupy a key role in this strategy, and would ‘enable technology needs to be identified, supported and developed more efficiently and at lower cost through effective collaboration (DTI, 1999, pp. 9-10).

However despite a clear need for an organisation of this type, a number of organisations can be seen to have been forerunners of ITF, with varying degrees of success. Most notably, the Marine Technology Directorate (MTD), the Petroleum Science and Technology Institute, and the Centre for Marine and Petroleum Technology (CMPT).

MTD was established in 1976 by the then Science and Engineering Research Council (SERC) as an internal directorate responsible for managing all marine engineering and oil and gas R&D funding within UK universities. MTD developed the idea for the Managed Programme (similar to a joint industry project) for funding universities with a combination of SERC and industry funding which was so successful that it was spun out as a separate organisation part funded by industry in 1984. It still had access to and managed research council money totalling around £6 million which with industry contributions was increased to around £9 million.

MTD ran in this format until in 1996, the now Engineering and Physical Sciences Research Council (EPSRC) made the decision to take the management of the funding back in-house, and cut the amount of funding given to oil and gas related R&D projects. The effect on MTD was substantial. Without the money provided by EPSRC, the justification for industry funding of the overheads was limited. Naturally enough, MTD had to find an alternative method of survival, and turned to PSTI.

PSTI (the Petroleum Science and Technology Institute) was established in 1989 by Heriot-Watt and Edinburgh Universities, and funded by industry. The organisation had a broad remit, covering the development of a core research programme and an information infrastructure, as well as conducting contract research and consulting.

Although MTD had traditionally had a more academic role, the two organisations had been seen by many (particularly those organisations who were sponsoring both) as having the same function. Consequently, MTD were able to negotiate a merger between the two organisations, which was supported by industry as a cost-saving initiative, and formed a new organisation: CMPT.

Unlike MTD and PSTI, the Centre for Marine and Petroleum Technology focussed on brokering research rather than acting as a project manager. It identified its core business as:

- 'providing Member companies in the upstream oil and gas industry with opportunities to access the advances in scientific and engineering knowledge and know-how, and the innovative technology which will bring significant benefit to their business;
- supporting the providers of research and innovation to bring their new ideas, their capability or novel technology to the industry, working with these providers to ensure timely, efficient delivery and most of all relevance to the industry's real needs.' (CMPT, 1998)

CMPT's existence was however short lived. The costs associated with establishing a new organisation combined with outstanding costs from MTD ensured that only two years later, CMPT collapsed. Although this could have been seen as a serious setback for technological innovation within the industry, the demise of the organisation was timely in terms of the recommendations by the OGITF Innovation and Technology Workgroup who (as stated above) drew up the business plan for ITF which is discussed in the next section.

OGITF was replaced in 2000 by PILOT. PILOT continues as a joint programme involving operators, contractors, suppliers, trade unions and SMEs. The function of PILOT is to monitor the progress made by the industry in achieving the vision identified for it by OGITF. OGITF identified a vision for the industry for 2010: 'The UK oil and gas industry and Government working in partnership to deliver quicker, smarter and sustainable energy solutions for the new century. A vital UK Continental Shelf is maintained as the UK is universally recognised as a world centre for the global business' (DTI, 1999). As well as this, PILOT identifies new areas of activity for the industry in order to aid in achieving the vision, and provides the industry with a forum for discussion.

Of course, as BERR (now BIS) itself suggests, there are substantial problems with making predictions concerning the future of the UKCS, and concomitantly, the offshore UK oil and gas industry: 'Nobody has yet produced a good predictor for oil prices which, of course, drive the industry. Furthermore, oil companies react more quickly to changes than most other business sectors. One has only to look at how technology has evolved and costs have been driven down in response to falls in oil prices.' (BERR, 2001)

What is certain however, is what reserves have been depleted, what reserves still remain, and how they may be more fully exploited: 'Excluding frontier areas noted above, the future development potential of the UKCS lies mainly in the exploitation of small fields located near existing infrastructure. Such developments will rely heavily on innovative technology and the sustained use of the extensive infrastructure associated with existing mature fields. The window of opportunity for this is limited and success will hinge on the need properly to integrate new satellite fields with mature fields. This will require both technical and commercial effort and flexibility' (DTI, 1999)

3.3.4 The Industry Technology Facilitator (ITF)

With clear links to several (if not all) of the previously identified initiatives and organisations, the last organisation to be discussed within this appendix is The Industry Technology Facilitator (ITF). Established in 1999 by the DTI, OGITF (discussed above), as well as a number of exploration and production companies operating in the UKCS, ITF is a not for profit organisation owned by 14 operating companies and three service companies. ITF describes itself as 'a conduit between technology innovators and the oil and gas industry' (ITF, 2008). It states that its key objectives are 'to identify technology needs, foster innovation and facilitate the development and implementation of new technologies into the oilfield' (ITF, 2008). Furthermore, it states that this last objective may be achieved through the following means:

- Identify the shared technology needs of our member companies
- Seek out innovative solutions
- Access the technology development funds
- Launch collaborative joint industry projects
- Create field trial opportunities
- Deliver technology implementation

The purpose of ITF is to 'facilitate major technological advances in the upstream oil and gas industry through the establishment of collaborative joint industry projects.' ITF facilitates joint industry projects (JIPs) by connecting technology providers (or developers) with funding bodies as well as, most importantly, the end users of the technologies.

ITF can be seen to play a pivotal role within this research. The organisation is the current incarnation of an agency which seeks to drive forward technological innovation within the industry. By doing this it seeks to support the agenda of OGITF (now PILOT), an initiative which encompassed both public and private sector bodies linked to the industry, and one which sought to address both short and long term factors associated with the survival of the industry as a whole.

4 Summary

To conclude both sections of this appendix, the oil industry has risen from very humble beginnings to become not only the largest, but one of the most (if not *the* most) important industries in the world. For Britain, the industry can be seen to be closely linked to its economic prosperity, even before the discoveries in the North Sea. Over the last forty years, this relationship has grown even stronger with the development of the UKCS. However, the sector is considered to be 'mature' and as such the continuing challenges are for both the private and public sectors in Britain alike to capitalise on the expertise and knowledge gained in the development of the area, as well as exploiting remaining oil and gas reserves in the most efficient ways possible through the use of innovative new technologies.

It is perhaps ironic that the harsh conditions which have characterised the UKCS have lead and are continuing to lead to the development of a source of expertise, knowledge and technology which may be utilised worldwide. Because of these conditions, the expertise associated with exploration and production within the North Sea may continue for many years after all the oil and gas can no longer be obtained from this region.

A variety of industry groups, initiatives and organisations have been identified which have attempted to address these issues in different ways with varying degrees of success. The role of The Industry Technology Facilitator can be seen to be a critical element of the industry's ongoing attempt to facilitate the development of new technologies in order to maximise oil and gas recovery within the UKCS, and as such can be seen to play a key role in this research.